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Full Length Research Paper

Why is adoption of agroforestry stymied in Zambia? Perspectives from the ground-up

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Small-scale farmers in Zambia are faced with problems of low crop productivity, scarcity of fuel wood and fodder, and subsequently are generally food insecure. Agroforestry can contribute to food and income security, amelioration of the environment and subsequently, to mitigation of climate change effects. However, despite all the potential of agroforestry technologies and the effort to promote them among smallholder farmers, their adoption and diffusion have remained low and so has their impact. Unless farmers adopt some of these technologies as part of their farming system, the potential benefits of agroforestry to food security, livelihoods and the environment will not be realized. This study investigated trialing and adoption levels of agroforestry in eastern Zambia where agroforestry has been researched and promoted for over two decades. A survey was completed of 388 small scale farmers. Data analysis shows that testing of improved fallows and biomass transfer, though low at 44.9 and 21.4% respectively, was higher than that of domestication of indigenous fruits (4.4%), Fodder banks (3.9%) and Woodlots (3.1%). The study however found that adoption rate of agroforestry among farmers that initially tested is high. Factors that affect adoption include lack of seed, limited land size, method of ploughing, lack of interest and access to extension services. Therefore we advocate for intensified promotion and encouragement support so that more farmers can trial these technologies. With high trialing rates, adoption of agroforestry is likely to increase. The key policy implication of this study is the necessity to embark on educating farmers so that they can trial and subsequently experience the impact of agroforestry technologies. Agroforestry will only make meaningful contribution to improving land productivity and farmer livelihoods if it is adopted.

Key words: Adoption, agroforestry, biomass transfer, improved tree fallows, logistic regression, smallholder farmers, Zambia.

INTRODUCTION

Although small-scale farmers face problems of low crop productivity, scarcity of fuel wood and fodder, and subsequently are generally food insecure, they have not been sufficiently stimulated to adopt agroforestry technologies that can enable them to increase yields with minimal external agricultural inputs. In Zambia, agroforestry technologies have been trialed at research stations since 1988, and on farms since 1992 in collaboration with farmers (Franzel et al., 2002). Agroforestry techniques have been deliberately promoted since 1997 by government agricultural extension systems, international organisations, Non-Governmental Organisations (NGO) and Community Based Organisations (CBO) to extend this knowledge to smallholder farmers (Böhringer, 2002; Franzel et al., 2001; Sanchez, 2002; Franzel et al., 2004). In 2004, eastern Zambia alone had over ten (10) organizations engaged in extension of agroforestry. Evidence of extension efforts in other countries have been reported by Chitakira and Torquebiau (2010), Masangano and Mthinda (2012), Mutua et al. (2014) and Kennedy et al. (2016).

Agroforestry can contribute to food and income security, amelioration of the environment and subsequently, to mitigation of climate change effects. Small scale farmers depend on land for their livelihoods and its ability to sustain production of food, feed, fibre and other goods. Agroforestry can improve crop productivity (Ajayi and Catacutan, 2012); Sileshi and Mafongoya, 2006; Kuntashula et al., 2006); enhance other ecosystem services (Sileshi et al., 2007); increase household access to wood energy; integrating fodder trees can improve animal feed availability as well as pasture productivity; agroforestry trees, when planted in the right place can reduce soil erosion and sequester substantial amounts of carbon. The potential of agroforestry in insulating smallholder farmers and agricultural landscapes against the negative impacts of climate change is also established to some degree in Zambia (FAO/IAEA, 2008). Farmers that get to adopt agroforestry can also benefit from the emerging carbon markets such as REDD+. A recent study in Zambia ranked agroforestry first among possible land use strategies for REDD+ (Kokwe, 2012).

There are five agroforestry technologies available for smallholder farmers in Zambia namely: improved fallows; biomass transfer; woodlots; fodder banks; and use of indigenous fruit trees (Kwesiga et al., 1993). The technologies developed for soil fertility improvement were improved fallows and biomass transfer (Kwesiga and Coe, 1994; Kwesiga et al., 1999; Kwesiga et al., 2003). Improved fallows are a deliberately planted crop of fast-growing leguminous nitrogen-fixing woody trees or shrubs left to grow on a field for a minimum of two years for rapid replenishment of soil fertility whereas biomass transfer refers to mulching or green-leaf manuring using tree or shrub foliage which is cut and incorporated to the cropping field so as to improve soil fertility (Kwesiga et al., 2003). In addition to soil fertility improvement technologies, there were other technologies that were tested including: establishment of woodlots for supply of fuelwood (Kwesiga et al., 2003; Nyadzi et al., 2006; Nyadzi et al., 2003b Pye-Smith, 2010); fodder banks as source of supplementary feed for animals (Chakeredza et al., 2007; Hove et al., 2003; Kwesiga et al., 2003); and domestication of indigenous fruit trees for nutritional security as well as contributing to household income (Iranbakhsh et al., 2009; Mng'omba et al., 2008; Akinnifesi et al., 2007; Kwesiga et al., 2003).

However, despite all the potential of these technologies and the effort to promote them among smallholder farmers (Zomer et al., 2009), their adoption and diffusion have remained low and so has their impact (Ajayi and Kwesiga, 2003; Mercer, 2004; Ajayi et al., 2007e; Ajayi and Catacutan, 2012). Unless farmers adopt some of these technologies as part of their farming system, the potential benefits of agroforestry to food security, livelihoods and the environment will not be realised. The objectives of this paper were to investigate the extent of adoption of agroforestry and the factors that lead to low adoption.

Adoption of agroforestry

There is confusion in the literature as to what constitutes 'adoption' by farmers (Giller et al., 2009; Jerneck and Isson, 2013; Glover et al., 2016). There also remains a gap in literature regarding understanding of adoption among subsistence farmers (Jerneck and Isson, 2013)). In this context, agroforestry has faced challenges, especially that different agroforestry technologies require different approaches and pathways to operationalisation. Different approaches to agroforestry adoption have been developed according to the technology under consideration (ICRAF, 2004). Distinctions have been made by some between testing farmers, experimenters and adopters (Adesina et al., 2000), whereas other authors have considered it as a continuum and hypothesized that farmers can be assigned positions on the continuum based on the uptake of the different components of the agroforestry technology (Ajayi and Kwesiga, 2003). Adoption definitions must take into or account the farmer's own perception of adoption. According to Ajayi (2007), farmers' definition of adoption follows such attributes as good management of the field, density of planting and mix of species planted, number of years the farmer continuously practices agroforestry and

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the size of the plot with agroforestry practices. These variations in definition of agroforestry adoption make comparison between studies difficult.

Sechrest et al. (1998) considered adoption as a dynamic process, whereas Rogers defines it as the implementation of already transferred knowledge about a technological innovation and that adoption is the end product of the technology transfer process (Rogers, 2003). According to Rogers (2003), adoption occurs when one has decided to make full use of a new technology as a best course of action for addressing a need. It refers to the process through which one is exposed to, considers, and finally rejects or accepts and practices an innovation (Mosher, 1978).

THE ADOPTION-DIFFUSION MODEL

The adoption-diffusion of innovations model (Rogers, 1962) is useful for understanding farmers' decision making processes when they consider testing and eventually adopting new technologies. Adoption is reached after an innovation-decision process that occurs in a presupposed five-step time-ordered sequence namely: knowledge; persuasion; decision; implementation; and confirmation (Rogers, 2003). This model assumes that the heart of the diffusion process lies in the modelling and imitation by potential adopters of their neighbours with the new practice (Rogers, 2003), and that the tendency to adopt new practices rely on: the relative innovativeness and; the personal attributes of farmers, with some farmers adopting innovations more quickly than others (Jangu, 1997). There is an assumption in this model that research generates information that is inherently valuable, desirable and suitable for increasing farm production and productivity (Jangu, 1997).

A farmer is said to have adopted an innovation after at least two repeated uses (Mosher, 1978). It is worth noting that farmers that have adopted a particular innovation may decide to discontinue or dis-adopt. Cary et al. (quoted in Guerin and Guerin, 1994) found in Australia a dis-adoption rate of 1 in 3 among farmers that had successfully adopted conservation tillage practices (Guerin and Guerin, 1994). Farmer rejection or dis-interest to trial it again may not necessarily be due to fault in the extension service but may include other factors such as topography (Mosher, 1978), socioeconomic and institutional (Matata et al., 2010; Mazvimavi and Twomlow, 2009).

Experiences with agricultural technology adoption in Southern Africa

There are many experiences where adoption claimed during the course of active promotion of technologies by NGOs and researchers, halted after the temporary influence of the project expired, without a sustained change in agricultural practice (Giller et al., 2009). When the project or research support stops, farmers quickly revert to their former crop management practices (Giller et al., 2009). The widespread adoption of conservation agriculture that was claimed through promotion programmes appears to have suffered the same fate in South Africa (Bolliger, 2007, quoted in Giller et al., 2009) and in Zambia (Baudron, 2008, quoted in Giller et al., 2009). Gowing and Palmer (2008 quoted in Giller et al., 2009) concluded that there has been virtually no uptake of conservation agriculture in most sub-Saharan African countries, with only small groups of adopters in Ghana, Tanzania and Zambia. Haggblade and Tembo (2003) suggest that 75,000 Zambian smallholder farmers practiced conservation farming in 2002/03 season, from about 20,000 in the 2001/02 season because of the 60,000 starter packs issued as a drought-relief measure by a consortium of donors. They estimated that some 15,000 were spontaneous adopters, while the remaining 60,000 practiced conservation farming as a condition for receiving their input. In many ways the problems that smallholder farmers face with adoption of conservation agriculture are analogous to the problems experienced with adoption of green manures or 'improved fallows' of fast-growing shrubby legumes (Giller et al., 2009).

Although there are many success stories of farmer uptake of green manures and improved legume tree fallows (also referred to as fertilizer trees) (Ajayi et al., 2006b; Ajayi et al., 2007), few of these have outlasted the lifetime of the promotion project (Giller et al., 2009). Where successes have been claimed there have been distortions of 'adoption' or 'farmer uptake' (Giller et al., 2009). In the late 1990s in Malawi during an intensive promotion campaign for intercropped green manures led by research scientists and NGOs, seed of the fish bean (*Tephrosia vogelii*.) was worth three times as much in the local markets as the main staple legume, common bean, and farmers responded by producing and selling Tephrosia seed (Giller et al., 2009). Although widespread farmer adoption of improved legume tree fallows was claimed in western Kenya, these vanished from the fields of smallholder farmers, together with the seed market for the legume trees, when the intensive promotion campaigns stopped (Ojiem et al., 2006 quoted in Giller et al., 2009).

The above examples point to the complexity of adoption, showing that farmers adopt technologies for different reasons and therefore reports on adoption need to be considered within given contexts and not generalised. A technology can only be considered a successful 'innovation' that is likely to spread spontaneously when fully embedded within the local social, economic and cultural context (Leeuwis, 2004, quoted in Giller et al., 2009).

Literature review on factors influencing trialing and adoption agroforestry

Adoption is influenced by several factors, including socioeconomic and environmental, that are governed by a set of intervening variables such as individual needs, knowledge about the technology and individual perceptions about methods used to achieve those needs (Thangata and Alavalapati, 2003). Successful adoption depends on favourable convergence of technical, economic, institutional and policy factors (Feder et al., 1985; Rogers, 2003).

Ajayi et al. (2003) have synthesised studies in Zambia on adoption of improved fallows. It was found generally that wealth, labour, farm size, and exposure to improved fallows affected farmer decisions to establish improved fallows (trial) and to later continue with the practice (adopt), while use of fertiliser and oxen ownership positively influenced a farmer's decision to establish a fallow. Phiri et al. (2004) found an association with farmers' wealth status with the fallow planting being higher among farmers that were classified as wealthier than among the very poor households. Similar results were obtained by Keil et al. (2005) who found that adoption of improved fallows increased with wealth levels, starting with those described as fairly wealthy, and decreased with well-off farmers. In addition they found a relationship between planting of improved fallows and the ownership of oxen (an indicator of wealth status among rural communities). Farmers who own oxen are able to cultivate larger pieces of land within a short time or hire out oxen for extra resources to pay for labour or purchase other inputs. This in turn enables them to find time and resources to establish and manage improved fallows.

Farmers that are involved in on-farm experimentation of agroforestry technologies with the researchers are more likely to adopt than those who are not (Phiri et al., 2004; Keil et al. 2005). Keil et al. (2005) reported a 75.5% adoption rate of improved fallows among experimenting farmers.

Farmer awareness of problems associated with land productivity encourages them to seek possible solutions to address such problems. Franzel (1999) revealed that when farmers are aware they have to improve their soil in order to increase production, and inorganic fertilizer was not available, they are likely to take up improved fallows. Farmers have several soil fertility improvement technologies to select from such as agroforestry technologies, crop rotation, animal manure, inorganic fertilisers and conservation farming (Mafongoya et al., 2006). Place and Dewees (1999) indicated that competition exists between all organically-based soil fertility replenishment systems and mineral fertilizer options, and a fertiliser subsidy acts as a disincentive to using organic-based systems. Keil et al. (2005) concluded that improved fallows could only be suitable in situations where there was inadequate access to markets for fertiliser, but that this result also depends on the wealth status of a household. Kwesiga et al. (2003) reported improved fallows as a technology for farmers that cannot afford fertiliser and have no access to animal manure.

In addition to bio-physical characteristics, farming systems are also constrained by socio-economic as well as cultural constraints (Giller et al., 2009). According to Giller et al. (2009) lack of uptake of some of the soil fertility management and productivity options result from farmers lacking the resources required to use a new technology and not due to technical problems with the new options. Marenya and Barrett (2007) also found that resource constraints were limiting many smallholder farmers in Kenya from adopting integrated soil fertility management techniques.

Sometimes, farmers do not adopt because the technology does not fit with existing practices. Farmers' involvement in new technologies requires tradeoffs with other activities from which they currently generate their livelihood (Giller et al., 2009) and if the new technology does not fit with them, they will hesitate to take it up. Doss and Morris (2001) have indicated that there are certain technology specific factors that influence adoption decisions. Rogers (2003) indicates attributes that farmers look for in a technology before they can apply it as relative advantage; trialability; observability; compatibility; and complexity.

Agroforestry technologies require access to germplasm, specific skill and knowledge (Styger and Fernandes 2006, Kwesiga et al. (2003) and their absence often limits the adoption of such technologies. Peterson (1999) found a lack of germplasm (seed and seedlings) as one of the reasons for farmers not practicing improved fallows. Ajayi et al. (2006c) list access to good quality seeds as one of the factors affecting adoption of agroforestry in Zambia.

Mercer and Miller (1998) have suggested that perceived risk and uncertainty about agroforestry could explain the low adoption rates. Pannell (2003) notes that uncertainty is one of the key factors inhibiting uptake of land conservation practices in Australia, but has not been extensively researched by agricultural related adoption studies due to the common focus on short-term productivity oriented practices. When farmers invest in planting trees that has uncertain outcomes, and requires them to wait before they can see yield results. Even when farmers are presented with information about the benefits of the technologies, they consider the labour investment for planting trees and the non-immediate returns, before they consider planting.

Negatu and Parikh (1999) and Zubair and Garforth (2006) attribute the low uptake and lack of participation in farm forestry activities to neglect of the perceptions of local people or potential beneficiaries of projects. Similarly, Keil et al. (2005) established that the probability of improved fallow adoption increases when farmers perceive low soil fertility as their current problem. The limited acceptance of agroforestry activities may be due to farmers' considering local conditions, cultural values, people's needs and the importance of local participation (Zubair and Garforth, 2006).

Opio (2001) reports insecurity of tenure as a hindrance to adoption of agroforestry in Zambia, hampering female farmers from participating in the establishment of *Sesbania sesban* fallows in Katete District of Zambia. Equally the synthesis by Ajayi et al. (2003) revealed that three studies had found farm size to have a positive association with farmers' decisions to plant and even continue with improved fallows although the latter finding is not associated with gender. Zambia has dual land tenure systems, the statutory and customary tenure systems (van Asperen and Mulolwa, 2006). Nearly all small-scale farmers fall within the customary tenure system whereby families depend on acquiring land through ancestry accession. As each family is restricted to sharing land that belonged to their forefathers, if family size increases, individuals' share of land gets smaller. Some farmers end up cultivating on borrowed or rented land. In communities where potential adopters cultivate such land, adoption of agroforestry is expected to be low. There is a need to establish the minimum required land size for a farmer to be able to engage in agroforestry practices and the percentage of farmers above that threshold. Equally important is the examination of whether the customary tenure system is sufficient in itself to support agroforestry.

Although Keil et al. (2005) found land to be a limiting factor to increasing the size of portions grown to improved fallows in Zambia, Styger and Fernandes (2006) found that in Central America, planted fallows even get adopted in areas where land is limited since farmers have to intensify their production and are forced to improve the only available pieces of land.

Farmers' planning time horizons are usually short and this influence how well environmental practices are fitted with other farm decisions (Vosti and Witcover, 1996). Franzel (1999) and Place and Dewees (1999) found that farmers rarely plan for fallowing the land but are forced to fallow when the harvests get too low, and when they cannot afford mineral fertilisers. If farmers do not plan for establishment of improved fallows, their inability to wait two years to see benefits constrains establishment of improved fallows (Peterson, 1999).

Gladwin et al. (2002a) report that what motivated the women farmers in Eastern Province to establish an improved fallow was the realisation that their soil was depleted; fertiliser was expensive and that their maize harvests could not meet their yearly consumption requirement. There appears to be a relationship between farmers' ability to purchase or access fertiliser and establishing a fallow. When farmers can afford fertiliser, they prefer to use it to improve crop productivity than establishing a fallow and waiting for two to three years before they can see the benefits.

Age has been found to be significant in deciding whether to continue with the technology or not (Ajayi et al., 2006a). Older farmers were not willing to continue with the technology as compared to younger ones.

Other factors influencing farmers' decisions to get involved with agroforestry include availability of labour supply (Ajayi et al., 2006a). Labour is considered a limiting factor, not only to a farmer's decision to practice agroforestry (Ajayi et al., 2003) but also to the expansion of the practices (Keil et al., 2005). Keil et al. (2005) found that only 14% of the adopting farmers were willing to expand beyond the experiment size, citing limited land and labour as constraining factors to any expansions. Styger and Fernandes (2006) also indicate that improved fallows get adopted where labour and technologies are readily available. Levels of poverty could also explain the low rates of adoption of agroforestry. According to Keil et al. (2005) farmers that were classified as poor and very poor had lower rates of adoption. Farmers have to wait to see the benefits of agroforestry technologies, hence they would need to have other ways of survival during the establishment stage of improved fallows.

METHODOLOGY

Study area, data collection and data analysis

A survey of 388 smallholder farmer households from districts of Chadiza, Chipata, Katete and Petauke located in the Eastern Province was conducted between the months of April to September 2008. Data were collected in eight (8) agricultural camps from four (4) districts indicated above namely: Chadzombe and Kumadzi; Feni and Kapita; Chilembwe and Mwanamphangwe; and Chataika and Mondola respectively. The sample composed of 57% male and 43% females. The distributions of respondents per district are 23.2, 25.3, 25.8 and 25.8%; for Chadiza, Chipata, Katete and Petauke districts, respectively. The districts and agricultural camps were purposefully selected based on their exposure to agroforestry. An agricultural camp is an area managed by one agricultural extension officer and normally consists of 200 to 300 households. The random selection of villages and respondents from each village was based on a list held by the agricultural extension officer, or where records were lacking a list was created and random selection of households was done following a random number sequence. Appointments were made through the agricultural extension officer for the farmers to be present at their households during the period of administering the questionnaires.

Data were collected by personal interviews through use of a structured questionnaire (Sekaran, 1992). Enumerators were recruited and trained to help with administering the questionnaire. Interviews were done in the local vernacular language, Chinyanja but the answers were recorded in English. A pre-test of the questionnaire was done to check for clarity and improve reliability. The timing of data collection was selected to coincide with the end of the rain season – a period when most farmers do not spend a great time on agricultural activities.

Table 1. (a) Testing of agroforestry technologies (percentages) where n=388 for each technology comprising the groups 'never tested' and 'tested'. (b) Adoption of agroforestry technologies (*with variable number of respondents).

Variables	Agroforestry technologies (%)				
	Improved fallow	Biomass transfer	Woodlots	Fodder banks	Indigenous fruits
a. Within the overall sample					
Never tested	55.2	78.6	96.9	96.1	95.6
Tested	44.9	21.4	3.1	3.9	4.4
b. Within the group who trialed a technology					
Adopted	73.6	89.2	91.7	80.0	82.4
Stopped	26.4	10.8	8.3	20.0	17.6
	(n=174)*	**(n=83)***	**(n=12)***	**(n=15*)**	**(n=17)***

Classification of farmers into adoption classes

A household was classified as testing agroforestry if they had trial-planted agroforestry tree species. Those households that have tested agroforestry, continued practicing it and have gone over one planting cycle of the agroforestry species, were classified as adopters, as described by Rogers (2003). Households that have tested agroforestry but had decided to discontinue using it were classified as 'stopped (dis-adopters). Rogers (1995) defines discontinuance as the decision to reject an innovation after it has previously been adopted. This study did not establish whether the group of farmers that tested agroforestry technologies had only intended to trial or they had intended to use the technologies. It is assumed that farmers who had tested the technologies had intended to use them.

It is hypothesised that there are differences between the three types of identified farmers, and that examining these differences could help explain the observed adoption levels for agroforestry in the study area. It is also hypothesised that both testing and adoption of agroforestry technologies are influenced by internal and external factors.

Data analysis

Cross-tabulations and chi-square tests were used to examine relationships among extension factors that influence agroforestry testing and adoption. Chi-square tests of independence were used to compare the frequency of cases found in the variables (Bryman and Cramer, 1997; Leech et al., 2008), and were used as a step of analysis for selecting variables for inclusion later into logistic regression (Field, 2005; Pallant, 2007). Factors that influence testing and adoption of improved fallows and biomass transfer technologies were investigated using logistic models. Logistic regression estimations were necessitated by the binary nature of the dependent variables (1=Trial/adopt; 0= not trial/dis-adopt) (Agresti and Finlay, 2009) as well as the fact that independent variables collected in the study were a mixture of nominal, ordinal and continuous ones (Hosmer and Lemeshow, 1989; Pallant, 2007; Agresti and Finlay, 2009). The logistic model was applied to the data using the LOGISTIC REGRESSION command in SPSS version 15 (Bryman and Cramer, 2009; Kinnear and Gray, 2008; SPSS, 2006) in the Windows 2003 environment. The logistic regression procedures on analysing and presenting results followed those described by Hosmer and Lemeshow (1989), Field (2009), Pallant (2007), and Sweet and Grace-Martin (2008).

RESULTS

Trialing and adoption levels

Generally both the initial testing and adoption of agroforestry in the study area are low (Table 1). This study focused on testing and adoption of two (2) agroforestry technologies namely: improved fallows and biomass transfer technologies. The sample population owned one to five plots per household and therefore every household was considered as having sufficient means to trial and adopt improved fallows. However, the proportion of the sample that had never tested this technology was higher than those who had (Table 1). For example, 44.9% of farmers reported they had tested improved fallows.

Biomass transfer technology is the other common agroforestry technology tested within the study area. In contrast to improved fallows, only 21.4% of the total sample had tested biomass transfer (Table 1). It is worth noting that not all farmers in the study area owned gardens. This study established that 285 (73.5%) of the sampled farmers had gardens. Therefore, the proportion of farmers who had tested biomass transfer among farmers and who owned gardens was 34.8%. In both cases however, that is, among the total sample as well as among those that own gardens, the proportion of farmers who have tested biomass transfer is low. The analysis for testing of biomass transfer however was done based on the total sample since the goal was to establish the proportions of farmers that had tested within the sample.

Factors influencing testing and adoption of agroforestry technologies

Two of the factors that appear to influence agroforestry adoption are the lack of seed and lack of knowledge. Figure 2 indicates that lack of seed and knowledge

Figure 1. Map of Zambia showing the study site of four districts in Eastern Province of Zambia.

influence adoption of improved fallows and biomass transfer more than other factors do. Each of the other factors' influence account for below 20% each.

Generally, the level of awareness in regards to both improved fallows and biomass transfer technologies was very high. The number of farmers that identified lack of awareness as factors influencing testing and adoption of both improved fallows and biomass transfers were less than five and ten percent respectively (Figure 1). Therefore lack of awareness is not the reason farmers would not trial improved fallows or biomass transfer. However, lack of knowledge and lack of seed of soil fertility nitrogen fixing trees were identified as affecting trialling of both technologies. Since lack of knowledge and seed were said to influence testing of both improved fallows and biomass transfer technologies they deserve particular attention when planning and implementing agroforestry development. The majority of farmers, irrespective of whether they had tested improved fallows and biomass transfer or not, did not think that any of the identified factors were influencing the decisions to trial the technologies.

Results of the logistic regression on adoption of improved fallows

The variables in the model to explain adoption of improved fallows (Table 2) are non-farm income (nfsinco), method of ploughing used (howploup), land limitation (landIF), lack of seed (seedIF), lack of interest (intrIF), and the frequency of visits by farmers to extension (farvists). In Table 2, the variable farmer visited extension (nofarv) substitutes variable farvists. Variables nfsinco, howploup and farvists are recoded into 5, 2 and 5 dummy variables respectively.

The model containing the six explanatory variables was found to be statistically significant (χ^2=74.781, df =15, p=0.000) (Table 2). This indicates that the model was able to distinguish between farmers who were classified

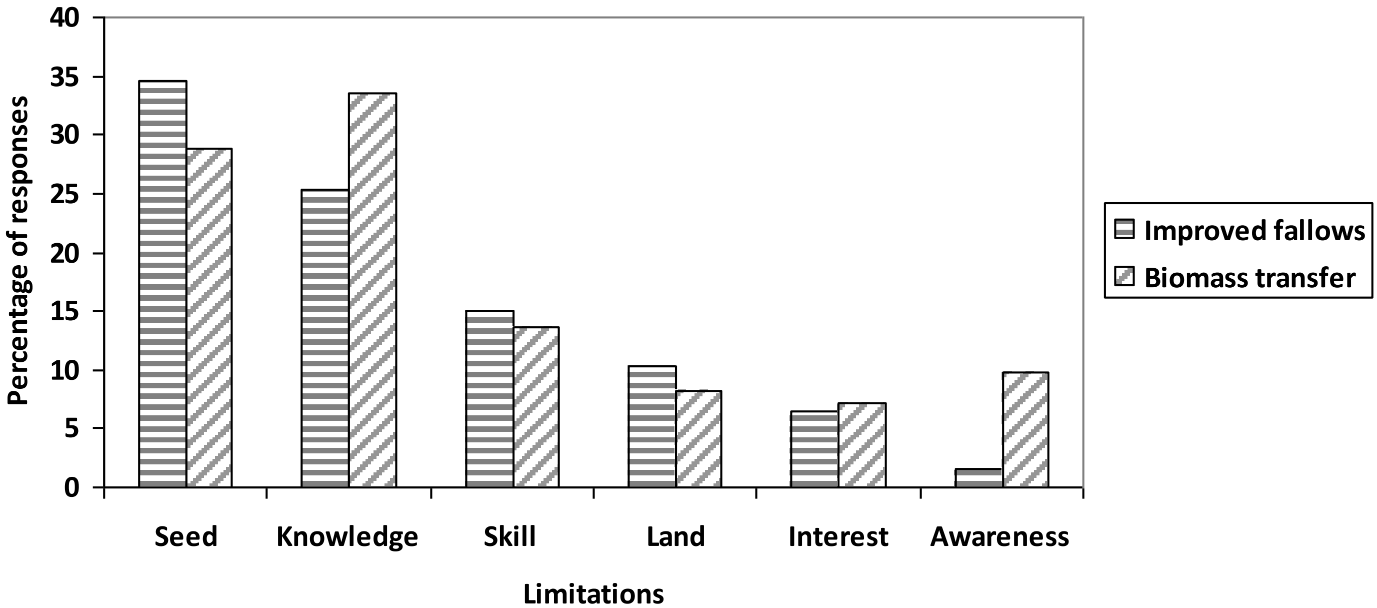

Figure 2. Factors influencing adoption of agroforestry in the study area of eastern Zambia.

Table 2. Logistic regression estimation for the adoption of improved fallows.

Parameter	B	Sig.	S.E.	Exp(B)
Non-farm income <100000 (nfsinco1)	1.081	0.234	0.909	2.949
Non-farm income 100001+ (nfsinco2)	1.721	0.023	0.755	5.591
Non-farm income ZMK500001+ (nfsinco3)	0.767	0.315	0.763	2.153
Non-farm income ZMK1000001 (nfsinco4)	0.352	0.776	1.241	1.422
Non-farm income >ZMK1500000 (nfsinco5)	2.051	0.084	1.188	7.773
Hand hoeing only (howploup1)	0.624	0.412	0.760	1.866
Combining hand hoeing and ox plough (howploup2)	-1.506	0.007	0.561	0.222
Land limitation (landIF)	-2.491	0.003	0.840	0.083
Lack of seed (seedIF)	-1.63	0.001	0.503	0.196
Lack of interest (intrIF1)	-4.734	0.000	1.345	0.009
Farmer visited extension officer 1-3 times (farvists1)	1.464	0.025	0.655	4.322
Farmer visited extension officer 4-6 times (farvists2)	0.439	0.651	0.972	1.552
Farmer visited extension officer 7-9 times (farvists3)	18.865	0.999	22687.59	155882993
Farmer visited extension officer 10-12 times (farvists4)	0.226	0.856	1.245	1.254
Farmer visited extension officer more than 12 times (farvists5)	2.122	0.026	0.951	8.348
Constant	1.317	0.007	0.485	3.734
Model Chi-square	74.781			
Model df	15			
Model Sig.	0.000			
-2 Log likelihood	126.215			
Cox and Snell R Square	0.349			
Nagelkerke R Square	0.510			
Hosmer and Lemeshow Chi-square	1.868			
Hosmer and Lemeshow df	7			
Hosmer and Lemeshow Sig.	0.967			
% correct predictions	83.9			

as having adopted improved fallows and those who had not. Cox and Snell R Square (0.349) and Nagelkerke R Square (0.510) indicate that approximately 34.9 and 51% variance in adoption of improved fallows can be predicted from a combination of the six independent variables. From Table 2, we note that overall, 83.9% of the respondents were predicted correctly. In the initial model 73.6% of farmers were correctly predicted as belonging to the group that adopted improved fallows.

The significant variables in the adoption of improved fallows model are shown in Table 2. The variables include: land limitation, lack of seed and lack of interest, visiting the extension officer between 1 to 3 times in a year, visiting the extension officer for more than 12 times in a year, and cultivation of fields using a combination of hand hoeing and ploughing. The strongest predictor of improved fallow continuance was the dummy farvists5 (farmers visited extension more than 12 times a year), which recorded an odds ratio of 8.348. The reference group for this dummy variable was novisits i.e. farmers that had never visited extension. This result indicates that farmers who adopted improved fallows were over 8.3 times more likely than those who had not adopted to report that they had visited the extension officer more than 12 times in a year. On the other hand, farmers that adopted improved fallows were also 4.3 times more likely than those who had not adopted to report they have visited the extension officer up to three visits per year.

In the case of the association between non-farm income and adoption of improved fallows, the groups that reported income between ZMK100,001 and ZMK500,000 and also over ZMK1,500,000 were found to be statistically associated with adoption of improved fallows. Their odds ratios were 5.6 and 7.7 respectively. The group without non-farm income were a reference group for this variable. Other income groups were not found to be statistically significantly different from the reference group.

The odds ratio of 0.222 for a combination of hand hoeing and ploughs to cultivate their fields was less than 1, indicating that farmers who adopted improved fallows were less likely to report that they used a combination of hand hoeing and ploughs to cultivate their fields.

Other predictors found to influence adoption of improved fallows were, limited land, lack of seed, and lack of interest. The odds ratios presented in Table 2 for these variables are less than 1, which suggests that the odds of adopting improved fallows are less for farmers who own little land, and lack tree seeds and also farmers who lack interest.

Adoption of biomass transfer technology

The variables in the model to explain adoption of biomass transfer technology are household yearly income ranging between ZMK 100,001-500,000 (yrlyinco2), household yearly income ranging between ZMK500,001 – ZMK1,000,000 (yrlyinco3), household yearly income above ZMK1,000,001 (yrlyinco4), lack of seed (seedBT), lack of interest (intrBT) and no extension visits (noextnv).

The model in Table 3 explained variability in adoption of biomass transfer of between 24.9 (Cox and Snell = 0.249) and 50.1 (Nagelkerke R squared = 0.501%). Equally, the Hosmer and Lemeshow test was not significant (p= 0.816) which according to Pallant (2007) implies support for the model. The model also correctly classified 90.4% of the farmers.

The variables yrlyinco2, yrlyinco3, yrlyinco4, seedBT, intrBT and noextnv were significant. The -2LL improved from 56.98 for that of the model with the constant only to 33.07. The Omnibus test of model coefficients is significant (χ^2 = 23.733, df = 7, p= 0.001), indicating that the model was able to distinguish between adopters of biomass transfer and those that were not. The combination of these variables explained variability in adoption of biomass transfer of between 25 (Cox and Snell = 0.25) and 50.4 (Nagelkerke R squared = 0.504%). Equally, the Hosmer and Lemeshow test was not significant (p= 0.825). The model also correctly classified 90.4% of the farmers.

It appears that annual household income, availability of agroforestry tree seeds and interest among farmers influence adoption of biomass transfer. For example, the odds ratios of 24.4, 47.95 and 140.2 with incomes of yrlyinco2, yrlyinco3 and yrlyinco4 respectively, were obtained (Table 3). The adopting farmers are 24 times more likely to report a higher income bracket of greater than ZMK100,000. It would therefore be expected that most of the farmers that have not adopted biomass transfer would report that they have no annual income. Lack of seed and lack of interest have negative signs and odds ratios below 1, implying that adopting farmers were less likely to report that they would be influenced by lack of tree seed and lack of interest in their decisions to adopt biomass transfer.

DISCUSSION

Trialing and adoption of agroforestry

Testing of both improved fallows and biomass transfer remains quite low. Despite the technological advantages of improved fallows and biomass transfer as established by research and some of the practicing farmers, farmers have not been testing these technologies to the extent that they can realise the benefits from them. Franzel et al. (2002a) reported improved fallows as a suitable practice for similar socioeconomic and biophysical conditions to those experienced by smallholder farmers in eastern Zambia. For those farmers whose fields had little or no yield, improved fallows are an obvious option to natural

Table 3. Logistic regression estimation for the adoption of biomass transfer.

Parameter	B	Sig.	S.E.	Exp(B)
Yearly income <100000 (yrlyinco1)	20.321	0.998	8705.206	669126989
Yearly income 100001+ (yrlyinco2)	0.445	0.827	2.038	1.561
Yearly income ZMK500001+ (yrlyinco3)	-0.076	0.973	2.241	0.926
Yearly income ZMK1000001 (yrlyinco4)	2.925	0.130	1.933	18.634
Limitation of seed (seedBT)	-2.453	0.134	1.637	0.086
Lack of interest (intrBT)	-22.935	0.998	9026.10	0.000
Extension officer visited farmer 1-3 times (farvistd1)	0.496	1.000	22615.9	1.642
Extension officer visited farmer 4-6 times (farvistd2)	-18.948	0.999	20736.6	0.000
Extension officer visited farmer 7-9 times (farvistd3)	-21.024	0.999	20736.6	0.000
Extension officer visited farmer 10-12 times (farvistd4)	-0.268	1.000	24349.2	0.765
Extension officer visited farmer more than 12 times (farvistd(5)	-16.207	0.999	20736.6	0.000
Had no extension visits (noextnv)				
Constant	19.514	0.999	20736.6	298551497
Model Chi-square	31.568			
df	11			
Sig.	0.001			
-2 Log likelihood	25.408			
Cox and Snell R Square	0.316			
Nagelkerke R Square	0.637			
Hosmer and Lemeshow Test				
Chi-square	1.037			
df	7			
Sig.	0.994			
% correct predictions	94			

fallowing as it would reduce the time of fallowing as well as considerably increase soil fertility, and subsequently increase yields. The assumption is that farmers would start testing of improved fallows as a response to soil fertility depletion. This means that farmers would start using improved fallows in fields that they have cultivated for a period of time even when they can still harvest a crop from it without the use of external inputs. This study found that 44.9% had tested improved fallows and 21.4% had tested biomass transfer. However, the retention proportions of farmers that adopt improved fallows after testing is higher than for those that stopped (Table 1). From this study, adoption of improved fallows was estimated at 73.6%, a result similar to Keil et al. (2005). Similarly, not all farmers that initially tested the biomass transfer technologies adopted them. Nevertheless, the discontinuance rate for biomass transfer (10.8%) is lower than that of improved fallows (Table 1). Floyd et al. (2003) also found similar results in adoption studies involving multiple agricultural technologies in Nepal where the probability of retention once a technology had been trialed was 60%. It appears that when farmers have trialed a particular technology, they are more likely to adopt it than if they did not try it at all. Both studies by Floyd et al. (2003) and Keil et al. (2005) concluded that testing the technology is an important step in the adoption process. The question remains therefore why not as many farmers get to trial these technologies in the first place; and how we could get them to trial the technologies.

Factors affecting adoption of improved fallows

Seed availability

Lack of seed emerged as one of the important reasons for farmers not testing both improved fallows and biomass transfer technologies. This finding is in line with Ajayi (2007) who reported that availability, sufficient amounts of and good quality seed were constraining the widespread uptake of improved fallows. The introduction of agroforestry technologies in the study sites started with ICRAF, an international research organisation, distributing seeds to the interested farmers mostly through formal extension and farmer groups. Groups were established particularly to promote agroforestry and the members of the groups were called farmer trainers. The role of the farmer trainers was to train fellow farmers and to distribute seed. Although lack of seed appeared to be a limiting factor for testing of improved fallows, it affected less than 40% of the sample. Some farmers in Zambia were discouraged from planting improved fallows due to late delivery of seed and that this mostly affected the seeds that required establishment of nurseries. Provision of small quantities of “starter seeds” as loans to farmers who are first time planters (Ajayi, 2007; Kiptot et al., 2006) the need for seed support systems through research and extension (Pisanelli et al. 2008) are necessary if improved fallows have to be trialed and subsequently adopted.

Farmer trainers/contact farmers get involved in capacity building activities that help to improve their understanding of the technologies they are intended to promote and therefore get exposed to various activities outside their communities such as tours, exchange visits, trainings and workshops. However, such farmers are perceived as being ‘better off’ and if jealousy arises some farmers do not feel comfortable associating with them (Kiptot et al*.,* 2006). Not all farmer trainers or first generation farmers plant the seed that is distributed to them. Kiptot et al. (2006) found that, although seed was distributed to the farmer trainers/contact farmers for free, 60.8% of the recipient farmers in Kenya had not planted them. When farmer trainers/contact farmers do not plant agroforestry species themselves but encourage other farmers in the area to plant, the likelihood that those other farmers would plant is low. The effect of free seed distribution in the Zambian context must be investigated to establish how adoption and the associated processes are affected.

The findings by Kiptot et al. (2006) concerning the choice of species by farmers are critical to improving the adoption of agroforestry. The study shows that farmers prefer to plant species of their choice, not those imposed upon them. Most farmers would prefer species with multiple uses, that are edible, saleable and with coppicing ability to those solely for soil fertility.

Agroforestry seed needs to be available through seed markets or farmer owned seed orchards if agroforestry technologies are to be part of the farming systems. Unless the seed is readily available to farmers and farming communities, agroforestry trialing and adoption will remain low.

Farmer interest in agroforestry

Lack of interest emerged as the second most important factor to lack of seed in influencing adoption. There is need to devise ways in which farmers’ interest can be aroused: perhaps through ensuring that they observe benefits accruing from use of improved fallows, and through provision of incentives that go with involvement in agroforestry programmes. Kiptot (2007) and Kiptot et al. (2007) found that smallholder farmers face the problem of addressing daily basic needs, hence their perception and prioritisation of technologies whose benefits are perceived to be in the far future are low. Ignoring the circumstance of smallholder farmers and simply addressing soil fertility issues, will negatively affect adoption of technologies such as agroforestry.

Lack of sustained interest could result in higher discontinuance rates and therefore promoters of improved fallows will require understanding on how to sustain farmer interest. One way would be to ensure that benefits of improved fallows are well established and demonstrable especially at the trialing stage. In addition, the impact of getting involved in improved fallows must be evident to those that adopt earlier.

Land Limitation

Land limitation was measured as a perception question, and farmers answered either ‘yes’ or ‘no’ to whether land was limiting them from testing improved fallows. This variable was only found to negatively influence adoption of improved fallows. It would appear that at testing stage, farmers are interested to see how the technology performs, however when they consider continuing with the practice, they assess land availability. It is necessary to help farmers with planning how to integrate improved fallows on land when they perceive it to be limited in relation to what they have to use it for. It needs to be emphasised to farmers that improved fallows can be applied to all sizes of land, especially now that there are species that have been found to effectively ameliorate soil fertility within one year’s growth.

Non-farm income

Non-farm income was found to positively influence the adoption of improved fallows. This contrasts with Baidu-Forson (1999) who did not find non-farm income to be associated with adoption of land-enhancing technologies in Nigeria and attributed this to the absence of options for households to earn non-farm income within the study region. Holden et al. (2004) concluded that access to non-farm income in the Ethiopian highlands reduced the incentives of farm households to invest in conservation. It can be argued that when farmers have sufficient income from non-farm activities, they will opt out of using technologies such as agroforestry which are labour intensive and require a longer period of time to realise the benefits, and engage in intensive agriculture including use of inorganic fertilizers. In eastern Zambia, non-farm income is usually earned during the dry season when there is little or no farm activity.

Annual household income positively influenced adoption of biomass transfer. Farmers usually obtain household income from sale of agricultural produce. In this study however it was established that farmers also obtained income from sale of livestock, off-season employment, and small businesses, but not from remittances. Ayuk (1997) also found in Burkina Faso that most of the household income comes from sale of agricultural produce and that 65% of households' income was derived from off-season farming. Use of biomass transfer is labour intensive, which means a household lacking family labour might need to hire from outside the family in order to manage it. In addition biomass transfer complements other garden activities and farmers usually have to invest in purchase of garden inputs such as inorganic fertilisers, vegetable seed and watering cans.

Method of ploughing

Farmers cultivate either by use of hand hoes, ox-drawn plough or a combination of the two. The adoption of improved fallows was found to be negatively influenced by the combined methods of ploughing. Farmers that used a combination of these methods would not adopt improved fallows compared to those who used either hand hoes or ox-drawn ploughs only. This study also found that most farmers depend on hand cultivation. The cultivation season starts during the dry season and usually the soil is hard to break but if farmers wait for the rains to start, they may be late to sow and plant their crop risking a reduction in crop yields. This therefore requires that they cultivate the land before the first rains or that they have the means to cultivate their fields fast enough for the crop to be grown with the first rains. Therefore, how farmers cultivate their fields gives them advantage to ensuring speedy and early planting.

Conclusions

This study has shown that there is a low level of adoption of agroforestry in eastern Province despite the high level of awareness about agroforestry in the study area. Improved fallows have a higher adoption compared to the other four technologies developed alongside it in eastern Province. This could be attributed to its direct contribution to increased yields of the staple crop – maize. The study found that adoption rate of agroforestry among farmers that initially tested is high. Therefore we advocate for intensified promotion and support so that more farmers can trial these technologies. With high trialing rates, adoption of agroforestry is likely to increase. The evidence provided suggests that with seed being made available to farmers, offering training on how to practice these technologies and exposing farmers to success stories where they have demonstrable effects, would increase the rate of trialing and subsequently adoption. Land distribution among small-scale farmers will remain an issue as over 50% of the farmers own less than two (2) hectares. Biomass transfer is not limited by land since it can be practiced even on small gardens exclusive of the tree component.

The key policy implication of this study is the necessity to embark on educating farmers so that they can trial and subsequently experience the impact of agroforestry technologies. However doing so requires more technical intervention as well as financial commitment by institutions and government agencies whose mandates require them to promote agroforestry. Agroforestry will only make meaningful contribution to improving land productivity and farmer livelihoods if it is adopted carefully.

Conflict of Interests

The authors have not declared any conflict of interests.

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Jatropha curcas performance in intercropping with forages grass and grain crops species

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The intercropping system has been accomplished with the objective to supply demand for foods through limited resources by smallholders conditions, associated with worries about improvement of land use efficiency. This study was carried out with the aim to assess the biometric and productive traits of *Jatropha curcas* in intercropping with species of forage grass and grain crops. The experiment was carried out in the district of Itahum, city of Dourados, state of Mato Grosso do Sul, Brazil. The treatments were *J. curcas* monocrop intercropping of *J. curcas* with *Stylosanthes* species, *Brachiaria ruziziensis*, *B. ruziziensis* + *Stylosanthes* spp., *Brachiaria humidicola*, *Panicum maximum* cv. Massai, *Cajanus cajan*, *Crotalaria spectabilis*, crop rotation system-1 (peanut/*Crambe abyssinica*/cowpea/maize), crop rotation system-2 (maize off-season/*C. abyssinica/soybean/peanut*) and crop rotation system-3 (cowpea/radish/maize/cowpea). The species in intercropping with *J. curcas* did not affect its biometric traits. *J. curcas* reaches higher seed yield in intercropping with crop rotation system-2 (maize off-season/*C. abyssinica*/soybean/peanut) and crop rotation system-3 (cowpea/radish/maize/cowpea) in comparison to the other species evaluated in intercropping. *J. curcas* seed yield is lower in intercropping with forage grass species.

Key words: Sustainability, cropping rotation, biodiesel, leguminous, oleaginous perennial.

INTRODUCTION

There are almost 200 species of oleaginous plants and Palmaceae with potential for biodiesel, as soybean, peanut, sunflower, sesame, turnip-fodder, castor oil, palm oil and *Jatropha curcas* (Ghosh, 2014). In this scenario,

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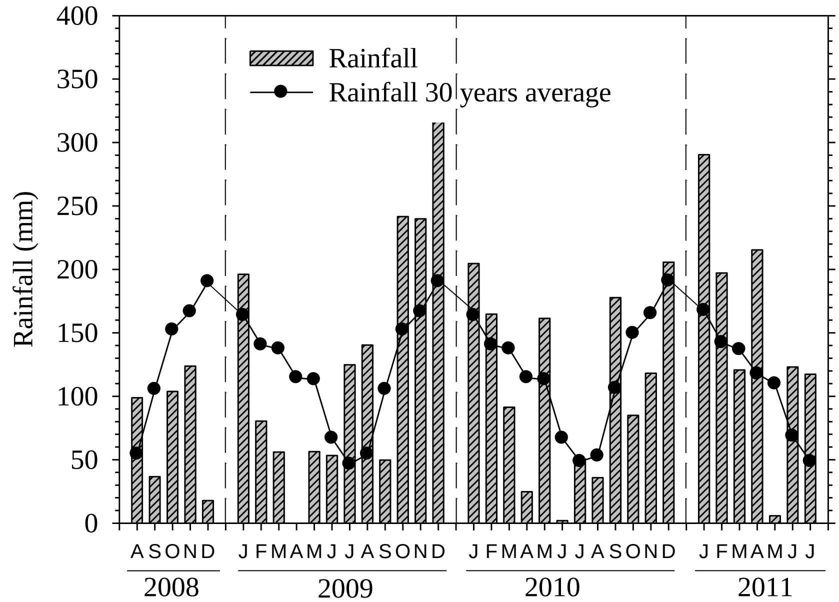

Figure 1. Monthly rainfall in 2008/2009, 2009/2010 and 2010/2011 growing seasons in comparison to the historical precipitation averages of 30 years. Source: Weather Station at Embrapa Western Agriculture Center, Dourados-MS, Brazil.

the challenge is to regionalize agricultural practices to be possible in the recommendation of adequate cropping system and adequate recommendation to improve cropping practice for these potential oil seed crops for biodiesel production.

J. curcas belongs to Euphorbiaceae family; this species shows large agricultural potential, highlight for seed yield, oil quantity and quality, aiming to biodiesel production (Tiwari et al., 2007; Castillo et al., 2014). The cultivation of *J. curcas* shows several advantages in relation to oil production: it is perennial, rustic, easy management, reaching 37.49% oil seed content, and high oil quality for biodiesel (Singh et al., 2016). *J. curcas* may be adequate for intercropping with other species because it is a shrubby plant and associated with wider space between rows the planting of other crops might be feasible (Silva et al., 2012).

The need to supply the demand for foods by means of scarce resources through smallholders is increasingly the adoption of intercropping systems for crop production (Machado, 2009). The intercropping has been used for many smallholders in Brazil, even more in relation to farmers who search higher land use efficiency and greater economic return (Veronesi et al., 2014), besides the generation of viable alternative to increase food offer. Nevertheless, seed yields obtained by stallholders in some locations in the world are limited because of feasible agricultural practice adopted (Liyama et al., 2013).

In relation to *J. curcas* production traits, oil yield depends on the vegetable features as number of branches, crown projection, plant height and crown volume, and production features; seed yield, seed weight, shell mass and seed oil content (Rao et al., 2008). The management adopted may result in negative or positive influence of crops in intercropping for production of the major crop; the positive effects may be related to improvement of soil chemical and physical properties, and negative ones might be due to possible water, light and nutrients competition (Tjeuw et al., 2015).

To improve positive interaction in intercropping, knowledge on the features of the crops associated is necessary, because without this information the farmers are going to commit many mistakes before achieving higher economic returns. This study was carried out with the aim to assess the biometric and productive features of *J. curcas* in intercropping with forage grass and grain crops species.

MATERIALS AND METHODS

Site description and soil

The experiment was carried out in the district of Itahum, city of Dourados, state of Mato Grosso do Sul, Brazil, at the coordinates 22°05’44" S and 55°18’48" W, enabled by a partnership between Brazilian Agricultural Research Corporation (Embrapa Western Agriculture) and Paraíso Farm. The soil is classified as Typic Haplortox (Santos et al., 2013), with average clay content of 200 g kg^{-1}. Long-term monthly rainfall averages, as well as actual rainfall recorded during the trial is presented in Figure 1.

J. curcas was sown in November 2006, on Paraíso Farm using a no-till system, by depositing three seeds per hill. After emerging, only the most vigorous seedling was left in each hill. Planting rows were spaced at 3 m and plants were spaced at 2 m within the row. In 2006/2007 and 2007/2008 growing seasons the usual

Table 1. Treatments of crop management systems in intercropping with *J. curcas* evaluated in the research.

Treatments	Abbreviation	Crop management system in intercropping with *J. curcas*
1	JM	*Jatropha curcas* in monocrop
2	IJS	Intercropping of *J. curcas* with *Stylosanthes* spp.
3	IJB	Intercropping of *J. curcas* with *U. ruziziensis* cv. Ruziziensis
4	IJBS	Intercropping of *J. curcas* with *U. ruziziensis* cv. Ruziziensis and *Stylosanthes* spp.
5	IJBH	Intercropping of *J. curcas* with *U. humidicola* cv. Humidicola
6	IJP	Intercropping of *J. curcas* with *Panicum maximum* cv. Massai
7	IJCC	Intercropping of *J. curcas* with *Cajanus cajan*
8	IJCS	Intercropping of *J. curcas* with *Crotalaria spectabilis*
9	IJCR-1	Intercropping of *J. curcas* with crop rotation system-1 (peanut/*Crambe abyssinica*/cowpea/maize)
10	IJCR-2	Intercropping of *J. curcas* with crop rotation system-2 (maize off-season/*Crambe abyssinica/soybean/peanut*)
11	IJCR-3	Intercropping of *J. curcas* with crop rotation system-3 (cowpea/radish/maize/cowpea)

management practices were applied to the field.

Experimental site and design

The treatments were installed in experimental plots comprised of four rows of *J. curcas* with six plants per row (144 m^2 per plot), the treatments are shown in Table 1. In order to evaluate plant height, crown diameter, stem diameter, and number of branches, the experimental was laid out in randomized complete block design with four repetitions, in a joint analysis in factorial scheme 11 × 2 (11 crop management system and two growing seasons). To assess 100-seeds weight, seed yield and seed oil content, factorial scheme 11 × 3 (11 crop management system and 3 growing seasons) was performed.

J. curcas fertilizer rate was applied annually with 32 kg N ha^{-1}, 80 kg P_2O_5 ha^{-1} and 80 kg K_2O ha^{-1}, through the formulation of 08-20-20 (400 kg ha^{-1}). The fertilizer was carried out manually close to the planting row. The fertilizer was divided in two applications for each growing season (2008/2009 and 2009/2010) (50% in October and 50% in January). In addition, 50 kg N ha^{-1} using urea as N source was applied in January 2009 and January 2010. Fertilizer rates recommendation followed the suggestion of Laviola and Dias (2008). The treatments with crop rotation (9, 10 and 11) were managed and fertilized according to recommendations for each crop. The remainder of the treatments did not receive any fertilizer rate. Intercropped forage grass and cover crops species were managed by mowing according to management height indicated by the research for each species. The resulted stubble was uniformly distributed on soil within the plot for mulching (Silva et al., 2012).

Variables assessed

In *J. curcas* trees, stem diameter was determined with the assistance of digital caliber in six plants in each experimental plot; this measurement was accomplished in plant collar. Plant height and crown diameter were determined with graduated ruler in six plants in each experimental plot that was measured from soil surface to the top branch of *J. curcas*. The crown diameter was measured transversely to the row, at the ends of the largest side branch of the plant. The number of branches from the most vigorous plants were determined by counting the vertical direction (from root to shoot) when the data were recorded and then filled in the final harvest of each growing season. In order to determine *J. curcas* seed yield, six plants in each experimental plot were harvest manually. Five harvesting time were conducted from December to July in each growing season (2008/2009, 2009/2010, and 2010/2011).

After harvesting, ripe and dried fruits in each experimental plot was stored in paper bags and naturally ventilated until constant weight. After the fruits dried, it was accomplished the threshing and weighted of the dried seed, and determined the seed yield and 100-seeds weight. The analysis of seed oil content in *J. curcas* grains were accomplished following the method of Soxhlet extraction, according to Lara et al. (1985).

Statistical analysis

The database were submitted to analysis of variance (ANOVA) and in case of significant difference ($p<0.05$) the means were compared by Tukey test of means with the assistance of the statistical software SISVAR.

RESULTS AND DISCUSSION

Biometric traits of *J. curcas* in intercropping system with forage grass and grain crops

The crop management systems evaluated in this study did not affect ($p>0.05$) biometric traits as plant height, crown diameter, stem diameter and number of branches of *J. curcas* on average of 2008/2009 and 2009/2010 growing seasons (Table 2). These results guide to an opportunity to integrate *J. curcas* in intercropping with grass and crops. Intraspecific and interspecific plant competition in intercropping is a challenge to be overcome to implement a profitable production system. The natural increment of plant height form 2008/2009 to 2009/2010 growing season was 19%, which was predictable since *J. curcas* reached its adult height in the fourth year after planting; this way in three years after planting the plants were in vegetable development. In the first growing season, *J. curcas* height did not differ among the crop managements evaluated, which may be due to the initial development of the grain crops and forage grass species

Table 2. Plant height (cm) of *Jatropha curcas* in intercropping with forage grass and seed crops.

Crop management system in intercropping with *J. curcas*	Growing season		
	2008/2009	2009/2010	Average of growing seasons
	Plant height (cm)		
J. curcas in monocrop	244.00^{Ab}	310.00^{ABa}	277.00^{A}
Stylosanthes spp.	259.25^{Ab}	306.00^{ABa}	282.63^{A}
B. ruziziensis	272.00^{Ab}	301.75^{ABa}	286.88^{A}
B. ruziziensis + *Stylosanthes* spp.	254.75^{Ab}	296.25^{Ba}	275.50^{A}
B. humidicola cv Humidicola	263.50^{Ab}	309.00^{ABa}	286.25^{A}
P. maximum cv. Massai	259.75^{Ab}	301.00^{ABa}	280.38^{A}
C. cajan cv. Anão	261.25^{Ab}	309.75^{ABa}	285.50^{A}
C. spectabilis	258.00^{Ab}	314.50^{ABa}	286.25^{A}
Crop rotation system-1	269.75^{Ab}	319.25^{Aa}	294.50^{A}
Crop rotation system-2	258.50^{Ab}	313.50^{ABa}	286.00^{A}
Crop rotation system-3	250.25^{Ab}	308.50^{ABa}	279.38^{A}
Average	259.18^{b}	308.14^{a}	-

Mean in each line followed by the low case letter compare growing seasons and mean in each column followed by capital letter compare the cropping management systems. Mean in each column or line followed by the same letter is not significantly different at p≤0.05 according to Tukey test of mean.

Table 3. Crown diameter (cm) of *Jatropha curcas* in intercropping with forage grass and seed crops.

Crop management system in intercropping with *J. curcas*	Growing season		
	2008/2009	2009/2010	Average of growing seasons
	Crown diameter (cm)		
J. curcas in monocrop	232.25^{Ab}	277.50^{Aa}	254.88^{A}
Stylosanthes spp.	234.50^{Ab}	262.75^{Aa}	248.63^{A}
B. ruziziensis	248.00^{Aa}	265.50^{Aa}	256.75^{A}
B. ruziziensis + *Stylosanthes* spp.	227.50^{Ab}	256.00^{Aa}	241.75^{A}
B. humidicola cv Humidicola	232.00^{Ab}	268.50^{Aa}	250.25^{A}
P. maximum cv. Massai	229.50^{Ab}	269.75^{Aa}	249.63^{A}
C. cajan cv. Anão	221.50^{Ab}	252.00^{Aa}	236.75^{A}
C. spectabilis	223.00^{Ab}	270.50^{Aa}	246.75^{A}
Crop rotation system-1	232.50^{Ab}	269.00^{Aa}	250.75^{A}
Crop rotation system-2	224.25^{Ab}	280.25^{Aa}	252.25^{A}
Crop rotation system-3	215.75^{Ab}	282.25^{Aa}	249.00^{A}
Average	229.16^{b}	268.55^{a}	-

Mean in each line followed by the low case letter compare growing seasons and mean in each column followed by capital letter compare the cropping management systems. Mean in each column or line followed by the same letter is not significantly different at p≤0.05 according to Tukey test of mean.

in intercropping with *J. curcas*. In 2009/2010, plant height in crop rotation system-1 differed from *Brachiaria ruziziensis* + *Stylosanthes* species, but in relation to the other treatments, no significant difference in plant height was observed (Table 2). The increase of *J. curcas* height indicated that these species evaluated in intercropping may not compete hardly for natural resources with *J. curcas* that can compromise its development in height. Nevertheless, interspecific competition in inter-cropping of *Jatropha* with crops has already been mentioned by Tjeuw et al. (2015), who found negative effects on *Jatropha* height due to moisture and nutrient competition with maize.

J. curcas intercropping system and monocrop did not affect the crown diameter of *J. curcas* on average of 2008/2009 and 2009/2010 growing seasons (Table 3). With exception of the intercropping of *J. curcas* with *B. ruziziensis* that remained without alterations, the other treatments showed higher crown diameter in the growing season 2009/2010 (Table 3).

Table 4. Stem diameter (mm) of *Jatropha curcas* in intercropping with forage grass and seed crops.

Crop management system in intercropping with *J. curcas*	Growing season		
	2008/2009	2009/2010	Average of growing seasons
	Stem diameter (mm)		
J. curcas in monocrop	105.04[ABb]	132.77[Aa]	118.90[A]
Stylosanthes spp.	111.71[ABb]	130.76[Aa]	121.23[A]
B. ruziziensis	102.79[ABb]	123.92[Aa]	113.35[A]
B. ruziziensis + *Stylosanthes* spp.	107.63[ABb]	118.09[Aa]	112.86[A]
B. humidicola cv Humidicola	107.84[ABb]	126.52[Aa]	117.18[A]
P. maximum cv. Massai	105.18[ABb]	123.13[Aa]	114.15[A]
C. cajan cv. Anão	106.00[ABb]	126.28[Aa]	116.14[A]
C. spectabilis	115.92[Ab]	131.15[Aa]	123.53[A]
Crop rotation system-1	111.42[ABb]	127.88[Aa]	119.65[A]
Crop rotation system-2	97.54[Bb]	128.59[Aa]	113.07[A]
Crop rotation system-3	105.13[ABb]	124.95[Aa]	115.04[A]
Average	106.92[b]	126.73[a]	-

Mean in each line followed by the low case letter compare growing seasons and mean in each column followed by capital letter compare the cropping management systems. Mean in each column or line followed by the same letter is not significantly different at p≤0.05 according to Tukey test of mean.

It is possible to infer that the spread of roots in deeper layers for *J. curcas* avoids higher competition for natural resources from soil. As reported by Sánchez et al. (2003), the establishment of roots from grain crops or forage grass species in surface layers and the trees in deeper layers decrease the competition in soil for water and nutrients. The increasing in crown diameter from 2008/2009 to 2009/2010 growing season was 16%, which is quite important due to the energy that the plant needs for growth that comes from the photosynthesis, this way, size of the crown diameter is related to the capacity of assimilate carbon and turn into energy (Larcher, 2004). Thus, the size of crown diameter is associated with the photosynthesize capacity, which is expected that higher crown diameter in relation to higher assimilation of CO_2 may result in increasing grain yield for *J. curcas*.

The crop management system evaluated showed significant difference only in 2008/2009 growing season, which showed depletion of the crop rotation system-2 on the stem diameter in comparison to intercropping of *J. curcas* with *Chrysolopus spectabilis*, the other treatments remained without alteration on stem diameter (Table 4). Nevertheless, this negative effect on stem diameter promoted by crop rotation system-2 was not confirmed in the following growing season (Table 4). In 2009/2010 growing season was observed increment of 19% of stem diameter in comparison to preceding growing season. However no significant difference was observed among the crop management system on average of the two growing seasons (Table 4). Based on stem diameter average of the two growing seasons, these results did not confirm competition for intercropping *J. curcas* with forages grass or grain crops species evaluated in relation to stem diameter of *J. curcas*. The stem diameter is positively correlated to root development (Fakuta and Ojiekpon, 2009), thus, plants with higher stem diameter is expected to have better nutrition and higher tolerance to drought stress due to higher root volume to explore the soil for water and nutrients. The absence of significant difference of crop management system in stem diameter of *J. curcas* pointed out a possibility for further researches to investigate the root development of vegetable species integrated in the production system to assure the absence of root competition through time of plant growth.

Numbers of branches were higher in 2008/2009 growing season for the treatments; intercropping *J. curcas* with *Stylosanthes* spp., *B. ruziziensis*, *Brachiaria humidicola*, *Panicum maximum* cv. Massai, *Cajanus cajan* and crop rotation system-3 (Table 5). Nevertheless, in the following growing season (2009/2010), the crop management system did not affect number of branches (Table 5). The number of branches on average of two growing seasons was not affected by the crop management system evaluated (Table 5).

These results reassure that intercropping of *J. curcas* with forage grass and grain crop species do not affect the development of *J. curcas* plants. Number of branches is a variable correlated with production capacity of *J. curcas* to develop its breeding structure in new branches growing up in the currently growing season (Dehgan and Webster, 1979; Tjeuw et al., 2015), thus the fruit production depends on number of new branches. The increment in number of branches from 2008/2009 to 2009/2010 growing season was 20%, which increases the capacity of *J. curcas* production under monocrop or intercropping system.

Table 5. Number of *J. curcas* branches in intercropping with forage grass and seed crops.

Crop management system in intercropping with *J. curcas*	Growing season		
	2008/2009	2009/2010	Average of growing seasons
	Number of branches		
J. curcas in monocrop	5.46^{Aa}	6.38^{Aa}	5.92^{A}
Stylosanthes spp.	5.42^{Ab}	6.54^{Aa}	5.98^{A}
B. ruziziensis	4.88^{Ab}	6.13^{Aa}	5.50^{A}
B. ruziziensis + *Stylosanthes* spp.	4.63^{Aa}	5.25^{Aa}	4.94^{A}
B. humidicola cv Humidicola	5.13^{Ab}	6.17^{Aa}	5.65^{A}
P. maximum cv. Massai	5.42^{Ab}	6.54^{Aa}	5.98^{A}
C. cajan cv. Anão	4.71^{Ab}	6.17^{Aa}	5.44^{A}
C. spectabilis	5.21^{Aa}	6.00^{Aa}	5.60^{A}
Crop rotation system-1	5.29^{Aa}	6.19^{Aa}	5.74^{A}
Crop rotation system-2	5.16^{Aa}	6.04^{Aa}	5.60^{A}
Crop rotation system-3	4.92^{Ab}	6.17^{Aa}	5.54^{A}
Average	5.11^{b}	6.14^{a}	-

Mean in each line followed by the low case letter compare growing seasons and mean in each column followed by capital letter compare the cropping management systems. Mean in each column or line followed by the same letter is not significantly different at p≤0.05 according to Tukey test of mean.

Table 6. 100-seeds weight of *J. curcas* in intercropping with forage grass and seed crops species.

Crop management system in intercropping with *J. curcas*	Growing season			
	2008/2009	2009/2010	2010/2011	Average of growing seasons
	100-seeds weight (g)			
J. curcas in monocrop	74.40^{Aa}	69.56^{Aab}	66.16^{ABb}	70.04^{A}
Stylosanthes spp.	74.31^{Aa}	69.92^{Aab}	67.07^{ABb}	70.43^{A}
B. ruziziensis	75.60^{Aa}	66.14^{Ab}	63.30^{ABb}	68.35^{A}
B. ruziziensis + *Stylosanthes* spp.	72.99^{Aa}	66.54^{Ab}	62.19^{Bb}	67.24^{A}
B. humidicola cv Humidicola	75.42^{Aa}	65.34^{Ab}	64.48^{ABb}	68.41^{A}
P. maximum cv. Massai	72.96^{Aa}	64.50^{Ab}	65.80^{ABb}	67.75^{A}
C. cajan cv. Anão	73.78^{Aa}	67.81^{Ab}	69.07^{Aab}	70.22^{A}
C. spectabilis	70.30^{Aa}	66.92^{Aa}	69.26^{Aa}	68.83^{A}
Crop rotation system-1	70.61^{Aa}	71.31^{Aa}	67.52^{ABa}	69.81^{A}
Crop rotation system-2	71.08^{Aa}	69.91^{Aa}	65.86^{ABa}	68.35^{A}
Crop rotation system-3	74.52^{Aa}	68.39^{Ab}	68.41^{ABb}	70.44^{A}
Average	73.27^{a}	67.85^{b}	66.28^{b}	-

Mean in each line followed by the low case letter compare growing seasons and mean in each column followed by capital letter compare the cropping management systems. Mean in each column or line followed by the same letter is not significantly different at p≤0.05 according to Tukey test of mean.

Productive features of *J. curcas* in intercropping with forage grass and grain crops species

In 2008/2009 growing season, 100-seeds weight of *J. curcas* was 8% higher than the following growing seasons (Table 6). 100-seeds weight showed significant difference through the crop management system only in 2010/2011 growing season, resulting in low 100-seeds weight in intercropping of *J. curcas* with *B. ruziziensis* + *Stylosanthes* spp. in comparison to intercropping with *C. cajan* cv. Anão and *C. spectabilis*. Even with decreasing in 100-seeds weight in intercropping of *J. curcas* with *B. ruziziensis* + *Stylosanthes* spp., the effect of crop management system on 100-seeds weight was not significantly different (Table 6). The average values of 100-seeds weight found in each growing season were above the average found in literature, as the case of Silva et al. (2008), who showed 46.89 g for 100-seeds weight of *J. curcas,* and 25.80 g for 100-seeds weight (Veronesi et al., 2014). These differences obtained in the study in

Table 7. Seed yield (kg ha^{-1} year^{-1}) of *Jatropha curcas* in intercropping with forage grass and seed crops.

Crop management system in intercropping with *J. curcas*	Growing seasons			
	2008/2009	2009/2010	2010/2011	Average of growing seasons
	Seed yield (kg ha^{-1} year^{-1})			
J. curcas in monocrop	229.19^{Ab}	329.72^{Aab}	388.16^{ABCa}	315.69^{AB}
Stylosanthes spp.	196.45^{Ab}	340.20^{Aa}	175.31^{CDb}	237.32^{BC}
B. ruziziensis	195.92^{Aab}	251.61^{Aa}	128.78^{Db}	192.1^{C}
B. ruziziensis + *Stylosanthes* spp.	207.44^{Aab}	317.45^{Aa}	134.83^{Db}	219.91^{BC}
B. humidicola cv Humidicola	214.97^{Aab}	262.87^{Aa}	134.67^{Db}	204.17^{C}
P. maximum cv. Massai	172.62^{Aa}	254.49^{Aa}	158.05^{Da}	195.05^{C}
C. cajan cv. Anão	192.81^{Ab}	339.15^{Aa}	205.56^{CDb}	245.84^{ABC}
C. spectabilis	204.33^{Aa}	311.59^{Aa}	258.93^{BCDa}	258.28^{ABC}
Crop rotation system-1	196.10^{Ab}	321.60^{Aa}	281.68^{ABCDab}	266.4^{ABC}
Crop rotation system-2	156.41^{Ab}	369.79^{Aa}	485.92^{Aa}	337.37^{A}
Crop rotation system-3	187.76^{Ab}	299.71^{Ab}	435.76^{ABa}	307.74^{AB}
Average	195.82^{c}	308.92^{a}	253.42^{b}	-

Mean in each line followed by the low case letter compare growing seasons and mean in each column followed by capital letter compare the cropping management systems. Mean in each column or line followed by the same letter is not significantly different at $p \leq 0.05$ according to Tukey test of mean.

comparison to the other results in literature might be due to different weather conditions that may influence on water and nutrients available for *J. curcas*.

The forage grass and grain crop species in intercropping affected the grain yield of *J. curcas* (Table 7). The significant effect of the intercropping was observed just in the third growing season (2010/2011), these results might be attributed to the species in intercropping be older and more established in the soil, which can recycle the nutrients and change in chemical and biological soil properties. Through the three growing seasons evaluated, *J. curcas* seed yield decreases in grain yield due to the intercropping with *Stylosanthes* spp., *B. ruziziensis*, *B. ruziziensis* + *Stylosanthes* spp., *B. humidicola* and *C. cajan* (Table 7), the decreasing may be attributed to water, light and nutrients competition among.

On the other hand, intercropping with crop rotation system-2 and 3 were observed higher seed yield of *J. curcas* in 2010/2011 growing season in comparison to 2008/2009. In growing season 2010/2011, the same treatments referred above showed higher seed yield. In general, in the present study seed yield of *J. curcas* showed values above the results obtained in literature, as the yield of 192 kg ha^{-1} observed by Oliveira et al. (2012) and 83.87 kg ha^{-1} showed by Evangelista et al. (2011). However, the soil properties can affect the seed yield of *J. curcas* (Openshaw, 2000), which can result in high diversity of seed yield in different regions. These observations on terms of seed yield might be an indicative that this intercropping with forage grass and seed crops species show great potential to be insert in intercropping system of *J. curcas* production.

The seed oil content in *J. curcas* was affected by the intercropping in all growing seasons. In 2008/2009 growing season, the seed oil content extracted from *J. curcas* monocrop and crop rotation system-3 showed lower seed oil content, while intercropping with *B. ruziziensis* showed higher oil content, in comparison to *J. curcas* monocrop, intercropping with *Stylosanthes* spp., *B. ruziziensis* + *Stylosanthes* spp., crop rotation system-1 and 2 (Table 8). In 2009/2010 growing season, the treatment of *J. curcas* intercropping with *B. ruziziensis* and *B. humidicola* showed higher seed oil content differing from the other treatments (Table 8). The average seed oil content were 33.24%, 34.84% and 29.37% in 2008/2009, 2009/2010 and 2010/2011 growing seasons, respectively. These averages are in accordance to Singh et al. (2016), who found 27.68% to 37.49% of crude seed oil content in *J. curcas*. On average of the three growing seasons, *J. curcas* monocrop and in crop rotation system-2 and 3 promoted lower seed oil content among the treatments evaluated.

Conclusions

The species in intercropping with *J. curcas* did not affect its vegetable development. *J. curcas* reach higher seed yield in intercropping with crop rotation system-2 (maize off-season/*Crambe abyssinica*/soybean/peanut) and crop rotation system-3 (cowpea/radish/maize/cowpea) in comparison to the other species evaluated in intercropping. The *J. curcas* seed yield is lower in intercropping with forage grass species due to interspecific competition.

The leguminosae *Cajanus cajan* cv. Anão and *Crotalaria spectabilis* showed intermediary result in terms of seed yield, which was attribute to lower interspecific competition with *J. curcas* and maybe biologic nitrogen fixation available for *J. curcas*.

Table 8. Seed oil content of *Jatropha curcas* in intercropping with forage grass and seed crops species.

Crop management system in intercropping with *J. curcas*	Growing seasons			
	2008/2009	2009/2010	2010/2011	Average of growing seasons
	Oil content (%)			
J. curcas in monocrop (control)	27.19^{Bb}	31.74G^{a}	27.03^{EFa}	28.65^{F}
Stylosanthes spp.	32.85^{ABa}	34.19^{CDEFa}	27.01^{EFb}	31.35^{CDE}
B. ruziziensis	38.42^{Aa}	37.36^{Aa}	32.35^{Bb}	36.04^{A}
B. ruziziensis + *Stylosanthes* spp.	33.02^{ABa}	33.71^{EFa}	31.59^{BCa}	32.77^{BCD}
B. humidicola cv Humidicola	34.83^{Aa}	37.72^{Aa}	28.81^{CDEb}	33.79^{ABC}
P. maximum cv. Massai	33.59^{ABa}	35.19^{BCDa}	35.77^{Aa}	34.85^{AB}
C. cajan cv. Anão	37.03^{Aa}	33.24^{Fb}	30.95^{BCDb}	33.74^{ABC}
C. spectabilis	34.64^{Aa}	35.44^{BCa}	28.01^{DEFb}	32.70^{BCD}
Crop rotation system-1	34.46^{Aa}	35.72^{Ba}	28.91^{CDEb}	33.03^{BC}
Crop rotation system-2	32.31^{ABa}	34.04^{DEFa}	25.16^{Fb}	30.50^{DEF}
Crop rotation system-3	27.28^{Bb}	34.73^{BCDEa}	27.51^{EFb}	29.84^{EF}
Average	33.24 b	34.83 a	29.37 c	-

Mean in each line followed by the low case letter compare growing seasons and mean in each column followed by capital letter compare the cropping management systems. Mean in each column or line followed by the same letter is not significantly different at p≤0.05 according to Tukey test of mean.

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Conflict of interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Evaporation of soil water based on the quantity and uniformity of crop waste distribution in soil superficies

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Plant residues influence the energy balance and water vapor flux on the soil surface. The aim of this research was to quantify the effect of the amounts and distribution of crop mulching on evaporation of soil water. The study was carried out at the Instituto Agronômico do Paraná, located in Londrina City, State of Paraná, Brazil. In experiment 1, soil water evaporation was determined according to the quantity of soybean and wheat residues applied (0, 2, 4 and 6 t ha^{-1}); while in experiment 2, soil water evaporation was determined based on the distribution of 4 t ha^{-1} residue of soybean and wheat, which was applied in 33, 66 and 100% as soil cover. Eight weighing lysimeters were used with two replications, and denominated cycles for each experiment period. The results showed that compared to bare soil, reduced evaporation at the end of the evaluations were 17% for 2 t ha^{-1}, 28% with 4 t ha^{-1} and 25% for 6 t ha^{-1} of residues of soybeans, in the first cycle during winter. During spring cycle, evaporation reductions in cycle 1 were 10, 12 and 23% for 2, 4, and 6 t ha^{-1}, respectively. Soil water evaporation decreased, compared to the bare soil, as soon as soybean residues rate increased. This showed the largest reduction (29 to 33%) when the residues were distributed uniformly over the lysimeters.

Key words: Lysimeter, water balance, soil moisture.

INTRODUCTION

Tillage system due to the maintenance of crop residue on the soil surface and its minimum tillage may lead to reduction of soil loss by erosion (Lal, 2007; Triplett Júnior and Dick, 2008) as well as runoff (Castro et al., 2006). On the other hand, the crop residue maintenance increases the rate of infiltration (Alves Sobrinho et al., 2003), and decrease the temperature range of soil (Torres et al., 2006), retaining more water (Freitas et al., 2004a).

Although there are several positive effects of straw on soil water evaporation, these inferences may not represent the loss of water. This is because the evaluations are based on gravimetric measurements in the soil moisture (Hillel, 1973), which are influenced by solar radiation, wind speed, temperature and humidity (Soares et al., 2001; Lyra et al., 2004), and also by the quantity (Freitas et al., 2004b) and distribution of plant

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residue in the soil surface.

The irregular distribution of crop residue in the soil surface causes the occurrence of localized accumulation; as consequence, problems like planter stuck, irregular seed emergence and rows under different soil fertility may occur. However, a proper distribution of residue in the soil surface operates as a physical barrier between the atmosphere and soil. This may prevent increased soil water evaporation, when soil is bare or in the initial phases of crop development (Stone et al., 2006; Souza et al., 2008). Soil water evaporation depends primarily on irrigation frequencies, soil texture and percentage of ground cover.

The irregular straw distribution through harvesters justifies the necessity of accurate measurements of soil evaporation and plant evapotranspiration using estimated models that can be obtained by lysimeters. The weighing lysimeters system allows measurements in short periods, usually less than one day, with greater accuracy. Lysimeters, developed by Fariaet al. (2006), have the accuracy to detect mass changes of 0.01 mm at intervals smaller than 1 h, which is adequate for most field applications.

In this sense, the evapotranspiration estimations in crops under incomplete cover may also be obtained by models of water movement in the soil-plant-atmosphere, which separate evapotranspiration in evaporation and transpiration components. Thus, the aims of this study were to quantify the effect of amounts and distribution of crop mulching on soil water evaporation in the region of Londrina, Paraná State, Brazil.

MATERIALS AND METHODS

The experiments were performed at the Agronomic Institute of Parana (IAPAR) located in Londrina City, State of Paraná, Brazil (latitude of 23°18'S, longitude of 51°09'W and altitude of 585 m) (Figure 1). The climate is classified as humid subtropical (Cfa) according to Köeppen classification and the average annual temperature is 21°C. Although the rainy season occurs between the months of October and March, with annual average rainfall of 1,500 mm, there is no occurrence of defined dry season (IAPAR, 2000). The soil of the experimental area was classified as Oxisol (Embrapa, 2013).

Measurements of evaporation on different levels of crop residue were performed in eight weighing lysimeters installed and maintained fallow. The lysimeters are metal tanks with dimensions of 1.4 m wide, 1.9 m long and 1.3 m deep. They were filled with local soil and placed at ground level (Figure 2), as described in detail by Faria et al. (2006).

Each tank is setup over a scale. The scales are a system of levers used for mass reduction; they are able to detect changes in mass equivalent to 0.1 mm at intervals of up to 1 h. The mass changes are measured by a load cell armored type "S" according to the manufacturer (Alpha Electronic Instruments Ltda, São Paulo, Brazil) and has capacity for 100 kgf tension, sensitivity of 10% ± 2 mV V-1 and IP67 protection index.

The load cells used had chart of calibration and certifying operation; however, preliminary tests in laboratory with known masses were performed to detect possible errors.

The storage variation readings occurred every three seconds and the data acquisition system (Datalogger CR21X Campbell Scientific, Logan, USA) stored the average of intervals of 10 min for each load cell, to avoid instantaneous fluctuations in measures caused by wind.

An external battery of 12 V powered the data acquisition system. The logger data were firstly transferred to a memory module, then to a computer by the software PC208W.

Test calibrations for each lysimeter were performed according to the procedure described by Mariano et al. (2015) before the experiment begins. Subsequently, the data were converted to millimeters using the values obtained in individual initial lysimeter calibration.

Soil water evaporation was determined by accounting for input, output and storage water in each lysimeter, according to the following equation:

$$E = P + I - R - D \pm \Delta A$$

where E is evaporation of water soil (mm); P is precipitation (mm) measured at the IAPAR weather station, located next to the experiment; I is irrigation (mm); R is runoff, considered zero because of the edge of the lysimeter tank; D is drain (mm); ΔA is variation in storage, given by the difference in weight in the period.

The evapotranspiration reference (ETo) was calculated daily by the Penman-Monteith method using the CLIMA software (FARIA et al., 2003).

Experiment 1 consisted of the determination of water evaporation from the soil with four amounts of crop residues (0, 2, 4 and 6 t ha^{-1}) in two periods: winter and spring (Figure 2).

To define the rate of crop residues used, we considered the average yield of wheat crop residue of 8 to 11 t ha^{-1} in a population density of 350 seeds m^2 (Heinemann et al., 2006) and soybean of 3.5 to 5.5 t ha^{-1} with a population density of 52 seeds m^2. These average values depend on genetic, edaphoclimatics and cultural practices factors.

The applications of soybean crop residues occurred during the winter and the wheat crop residues occurred during spring, respectively. Two replicates of each experimental treatment called cycles 1 and 2 were carried out. Before starting each cycle, lysimeters were covered with fine nylon net to prevent a possible removal of residues by wind.

Lysimeters were calibrated with soil moisture at field capacity. Moreover, at the beginning of each measurement cycle, a water depth of 50 mm was applied by sprinklers for a better accommodation of the residues on the soil surface. During this initial water application, treatments without residues were covered by the use of disks of natural and synthetic fibers, aiming to protect the area.

The experimental periods during the winter were May 13 to 22th (11 days) and from May 28 to June 7th, 2011 (13 days). During spring period, measurements were carried out from September 24 to October 10th (26 days) and November 21 to December 9th, 2011 (22 days). Crop residues of soybean and wheat were dried in oven with forced air circulation for 48 h at a temperature of 65°C until constant weight was obtained; then the quantities of residues required in each treatment according to the area of the lysimeters were determined.

In Experiment 2, evaluations were conducted to determine the water evaporation from the covered soil with 4 t ha^{-1} of soybean residues during the fall/winter, and wheat residues during the spring/summer, with three uniformity of distribution (33, 66 and 100%) and a control treatment without residues, similar to those described by Freitas et al. (2014). Like in Experiment 1, two replications of each treatment called cycles (Figure 3) were performed and mass measurements from lysimeter were initiated after the irrigation of 50 mm.

The cycles were performed during periods of June 12 to 21th

Figure 1. Location of Londrina city, State of Paraná, Brazil.

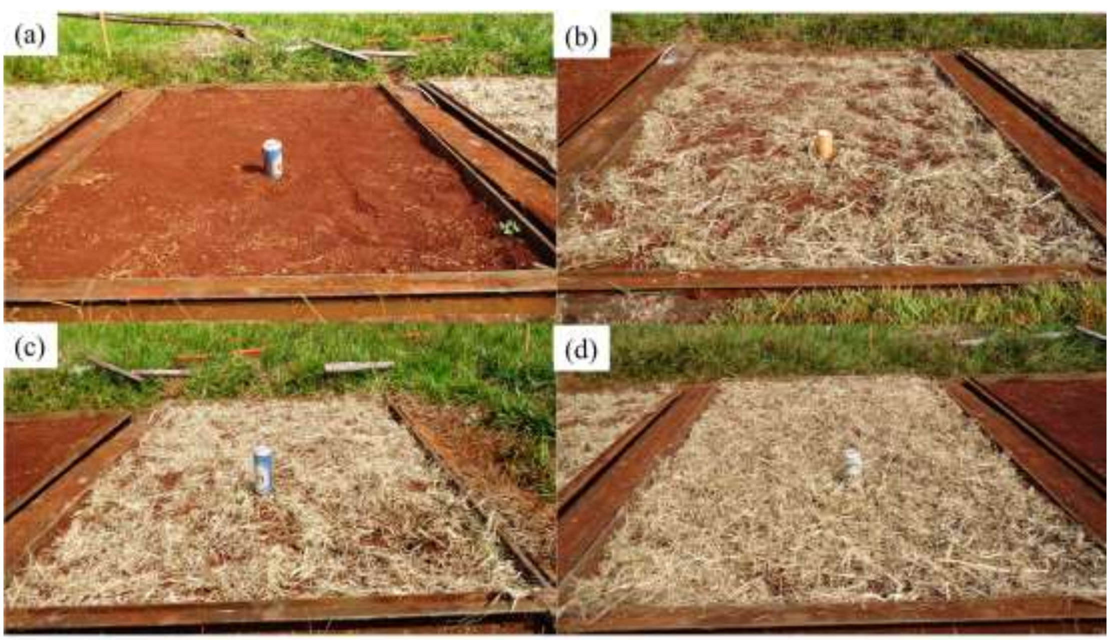

Figure 2. Lysimeters with bare soil (a) and under different amounts of culturewaste, 2 t ha^{-1} (b), 4 t ha^{-1} (c) and 6 t ha^{-1} (d).

(winter) and July 08 to 18th, 2011 (winter), a total of 9 and 10 days. While the cycles from the second period were conducted in October 21 to 29th (spring) and December 16^{th}, 2011 to January 09^{th}, 2012 (summer), a total of 8 and 24 days, respectively.

Crop residue of soybean and wheat were obtained and managed in the same way as Experiment 1. To determine the amount of residue required for the distribution, 33 and 66% were divided into five band lysimeters of 9.33 and 18.66 cm depending on the

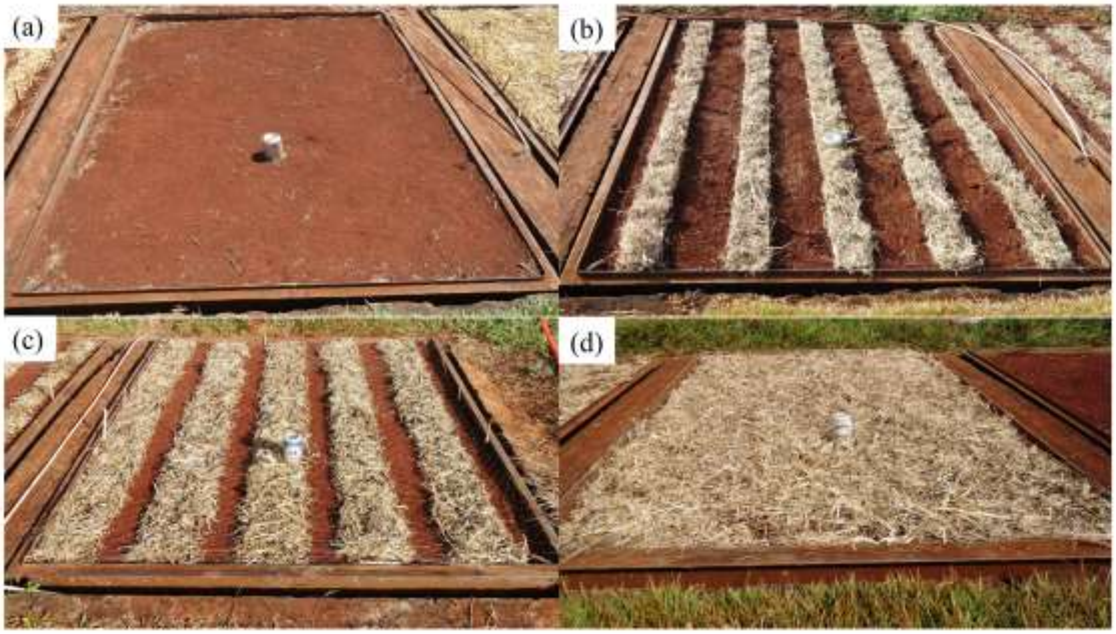

Figure 3. Lysimeters with bare soil (a) and under different toppings residues of soybean straw, 33% (b), 66% (c) and 100% (d)

distribution model proposed (Figure 3b and c); and calculation was performed by the total amount of residue (4 t ha^{-1}) applied in the lysimeter area.

At the end of each experimental cycle, soil samples at depths of 5 cm in each lysimeter were sampled to determine the soil moisture. In all the evaluations, lysimeter drainage was performed.

RESULTS AND DISCUSSION

Experiment 1

Soil evaporation was determined based on the different quantities of soybean and wheat residues in two cycles during winter and spring (Figure 4).

During each cycle evaluation, it was observed that evaporation increased with the occurrence of precipitation in all treatments. The water demand remained mostly constant during the evaluation periods, where the ETo average rates were 2.5 and 2.3 mm day^{-1} for cycles 1 and 2 in winter (Figure 4a and b). Furthermore, cycle 2 showed a rainfall accumulation of 15.4 mm in the last evaluation day (June 7th), a fact which disallows the beginning of a new drying period (Figure 4b).

Similar behaviors were observed during the spring; however, the average ETo rates were higher and ranged between 3.8 and 4.9 mm day^{-1} (Figure 4c and d).

In the evaluation, precipitations that increased evaporation in all treatments were recorded. In addition, it was observed that bare soil evaporation was greater than ETo, because of the high moisture conditions presented in the soil surface, which allowed a free water evaporation (Figure 4d).

In spring cycle 1, cumulative rainfall was 200 mm starting with irrigation on September 21th (Figure 4c). The precipitation volume recorded identified the reason for high rate of evaporation from all treatments. On the other hand, cycle 2 presented a cumulative rainfall of 45 mm, starting with irrigation on November 17th (Figure 4d).

The gradual reductions of evaporation rate based on time after the start of each cycle evaluated were due to the gradual soil surface layer drying (Figure 4). The effect was more pronounced in treatments with no residues, when soil water evaporation rate was equal to ETo on the first evaluation day, after the initial irrigation and rainfall that occurred over the two cycles. This indicates a short period (<1 day) for the phase 1 of the evaporation method proposed by Ritchie (1972).

The first stage of evaporation may take from one to three days and the magnitude of this period rates can reach 90% depending on the soil depth and hydraulic properties. In treatments with residue, the evaporation variation was not observed during the transition from stage 1 to stage 2, because evaporation rates were low from the early days, occurring fast decrease along the time until the surface became totally drought. In the evaluated treatments, the soil water evaporation decreased as much as soil moisture decreased, featuring the second stage of evaporation. This began close to the 5th day of drying, during the evaluation cycles (Figure 4).

The crop residues quantity effect on evaporation reduction is shown by the curves of cumulative

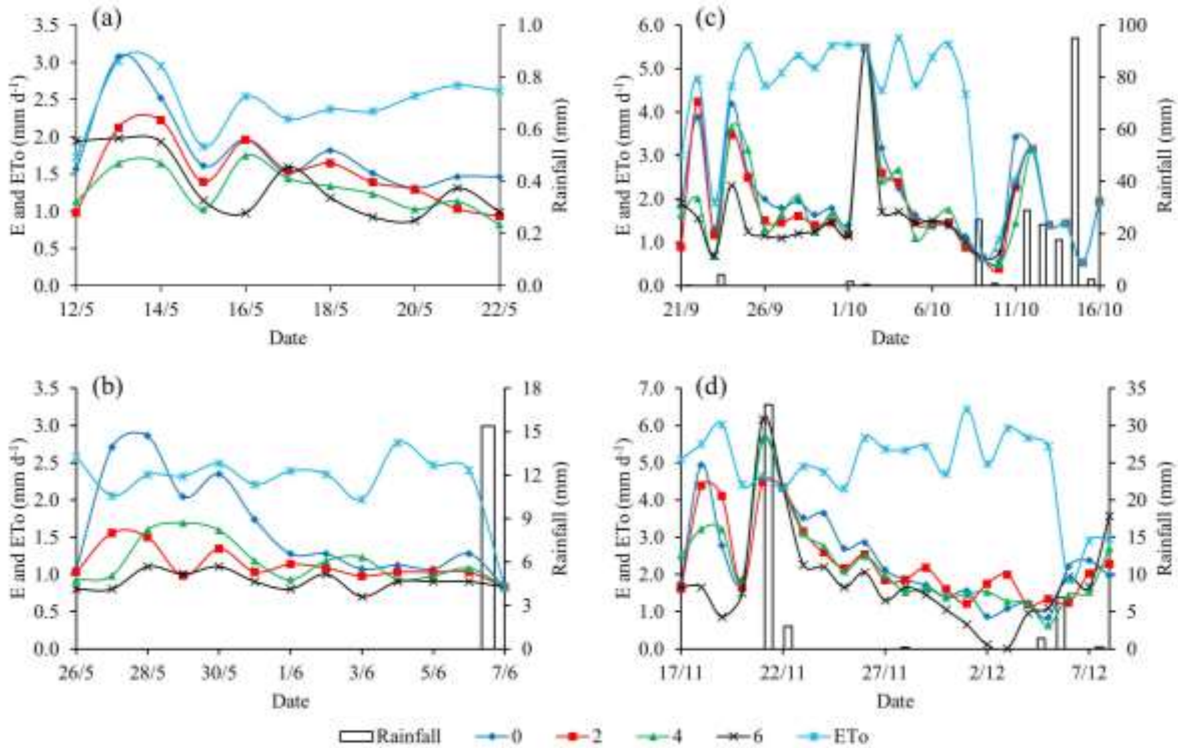

Figure 4. Evaporation (E) and reference evapotranspiration (ETo) assessed during cycle 1 (a) and cycle 2 (b) during winter using soybean residue and cycle 1 (c) and cycle 2 (d) during the spring under wheat residue.

evaporation at the end of the drying cycle, which is presented in Figure 5 during the winter treatments, using soybean residues.

ETo values were 26.9 mm for cycle 1 and 29.2 mm for cycle 2. The cumulative evaporation for treatments 0, 2, 4 and 6 t ha^{-1} with soybean residues during cycle 1 from winter was 19.8, 16.5, 14.2, and 14.9 mm, respectively (Figure 5a). Moreover, in cycle 2 were recorded accumulated evaporation values of 20.7, 14.6, 15.2, and 11.8 mm for 0, 2, 4, and 6 t ha^{-1} treatments, respectively (Figure 5b). Analyzing Figure 5a and b, it has been found that the cumulative evaporation was lower in treatments of 4 and 6 t ha^{-1}.

Drying cycles assessed during the spring showed reduced cumulative evaporation for 4 and 6 t ha^{-1} of wheat residues (Figure 5c and d), which emphasize the results obtained for the soybean waste (Figure 5a and b).

The ETo values accumulated during spring cycles were 98.8 and 106.7 mm (Figure 5c and d), consequence of an increased evapotranspiration. The cumulative evaporation during the cycle 1 for treatments 0, 2, 4, and 6 t ha^{-1} of wheat residue was 53.7, 48.1, 47.1, and 41.4 mm, respectively (Figure 5c). While in cycle 2, it was recorded cumulative evaporation of 53.2, 51.4, 49.6, and 39.8 mm for 0, 2, 4, and 6 t ha^{-1} of wheat residues, respectively (Figure 5d). Thus, it could be observed that cumulative evaporations obtained were similar, regardless of the differences between cycles.

The treatments carried out during the winter resulted in higher percentages of reductions in evaporation, in which cycles 1 and 2 under 4 and 6 t ha^{-1} treatments showed 28 and 43% evaporation reductions. During both spring cycles, 6 t ha^{-1} treatment showed reductions of 23 and 25%.

As daily ETo increased, the values of accumulated evaporation also increased, however, the soil moisture content (amount of water present in it) is the fact that drove the soil evaporation of each treatment. Overall, the cover residues were determinants before the fourth day after water application, because after this period, no effect from different soil cover residues on the phenomenon of water loss was observed.

The second-degree polynomial model showed average reductions of 23, 28, and 34% in evaporation for rates of 2, 4, and 6 t ha^{-1} of soybean residues in both cycles during winter compared to bare soil (Figure 6a). The spring cycles showed evaporation reduction of 7, 10, and 24% for 2, 4, and 6 t ha^{-1}of wheat residues, respectively (Figure 6b). The results confirmed data found by Freitas et al. (2004a); they were similar to those reported by Xie et al. (2006), who found reductions of 40.7% during the watermelon cycle under treatment with no coverage, and 17.8 to 25% for coverage treatments of sand and gravel, under cold weather conditions, where the maximum

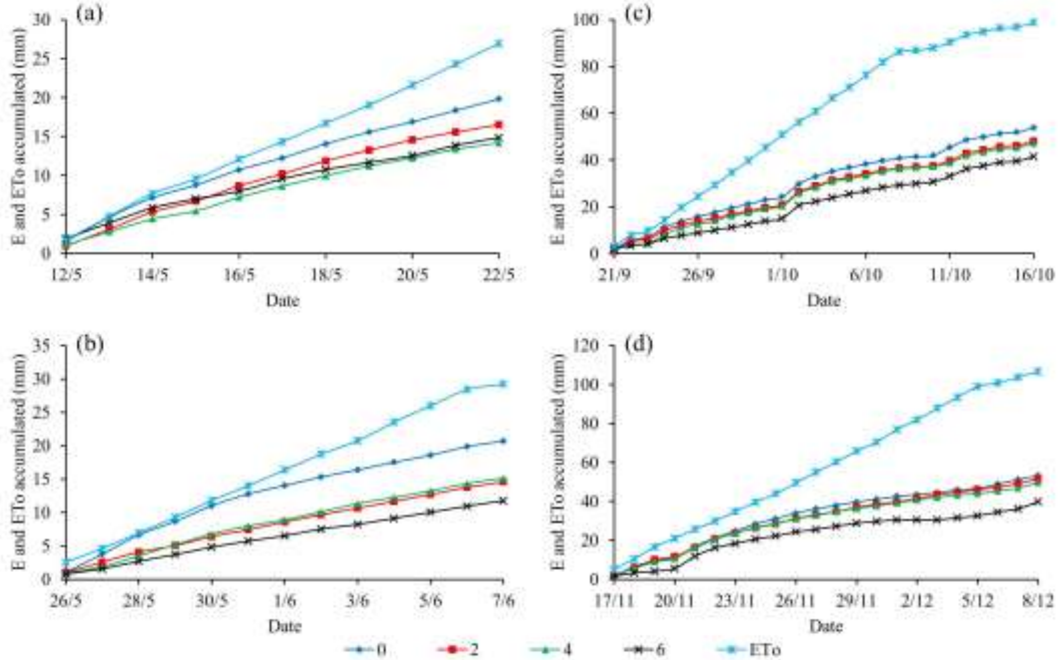

Figure 5. Reference evapotranspiration (ETo) and accumulated evaporation assessed during cycle 1 (a) and cycle 2 (b) during winter using soybean residues and cycle 1 (c) and cycle 2 (d) during the spring under wheat residue.

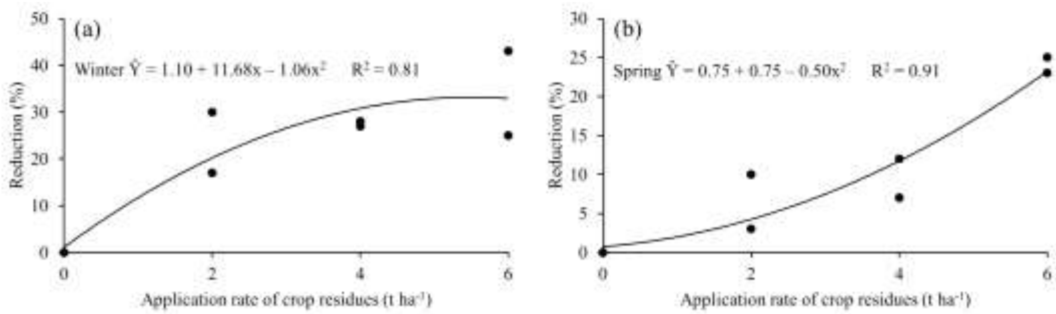

Figure 6. Evaporation reduction due to amounts of residues at the end of two cycles of drying during winter under soybean residues (a) and spring wheat residues (b).

annual temperature was 20.7°C.

Experiment 2

The effects of residues distributions on soil evaporation and ETo versus time were plotted for two cycles at the end of the drying with soybean and wheat residues (Figure 7). The percentage of evaporation in cycle 1 from fall/winter was 67% compared to bare soil (Figure 7a). The atmospheric demand during the study period showed small variations with ETo rates of approximately 2.4 and 2.5 mm day^{-1} for cycles 1 and 2, respectively (Figure 7a and b).

The cycle 1 from spring/summer presented evaporation rates of 95% for treatments with 33 and 100% of wheat residues, while 66% treatment had evaporation of 93% (Figure 7c). However, the lowest rates of evaporation occurred in treatments containing surfaces covered with wheat residues. In cycle 2, the evaporation rates were 74, 82, and 77% to wheat residues distributed at 33, 66, and 100% (Figure 7d).

When the soil surface showed high humidity, the evaporation exceeded the ETo, considering that the water was practically free to evaporate. On November 13, 14, and 24th and January 3, 5, and 15t^{h}, when precipitation occurred, an increased evaporation rates in bare soil were observed. On the other hand, after

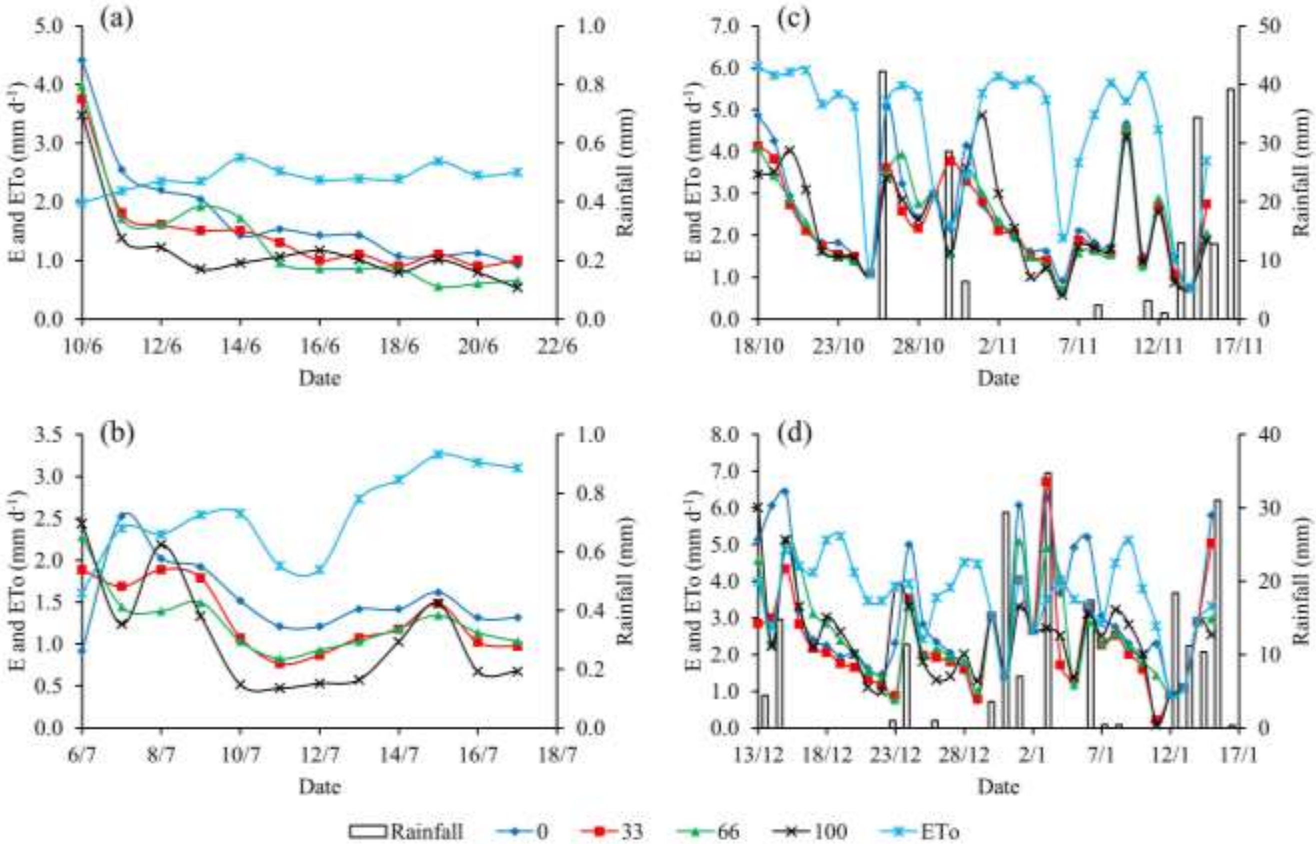

Figure 7. Reference evapotranspiration (ETo) and evaporation (E) assessed during cycle 1 (a) and cycle 2 (b) during fall/winter using soybean residues; and cycle 1 (c) and cycle 2 (d) during the spring/summer for wheat residues.

precipitation, treatments under residues application had the highest rates of evaporation, because those treatments retained the moisture for a longer period and supplied the atmospheric demand (Figure 7d). The occurrence of an increased evaporation in treatments under more distribution of residues can be attributed to errors from the lysimeters during rainfall periods, as mentioned by Faria et al. (2006).

Precipitations occurred during the evaluation period of spring/summer. It resulted in variable values of ETo over this period, which presented average of 4.50 and 3.56 mm day^{-1}, respectively (Figure 7c and d). Frequency of rainfall occurred in short periods (<1 day) from the evaporation stage 1.

After the beginning of each rated cycle, the gradual reduction of the evaporation rate versus time occurred due to the drying of the soil surface layers from lysimeters. These effects were more pronounced in treatments without residues, when evaporation rates were similar to ETo only on the first day of the cycle. That indicates a short period (<1 day) for the evaporation stage 1. However, in treatments containing residues, transition of evaporation stage 1 to stage 2 was not observed, because evaporation rates were lower from the beginning. This resulted in a fast soil water decreases during the drying timing, influenced by evaporation and soil hydraulic properties. During evaluations, the soil water evaporation decreased as soil moisture decreased, featuring the evaporation stage 2, which started near the 5th day of drying (Figure 7).

Comparing the fall/winter treatments under soybean residues and spring/summer wheat residues treatments, the values of evaporation were close, probably due to lower soybean residue coverage. During periods with more intense weather conditions, evaporation values were close to those found during warmer period. This demonstrates dependence between water evaporation from the soil surface and atmospheric evaporative demand, also observed by Dalmago et al. (2010).

The soybean residues were less effective to protect and hold water on the soil surface compared to the grasses. A quantity of 3.5 t ha^{-1} of soybean residue makes the soil surface to be unprotected by 35%, while the same amounts of millet and maize residues provided 25 and 20% of bare soils (Silva et al., 2006).

The effect of crop residue distribution on evaporation reduction is shown by the curves of cumulative evaporation at the end of the drying cycle during fall/winter period under soybean residues (Figure 8a and b).

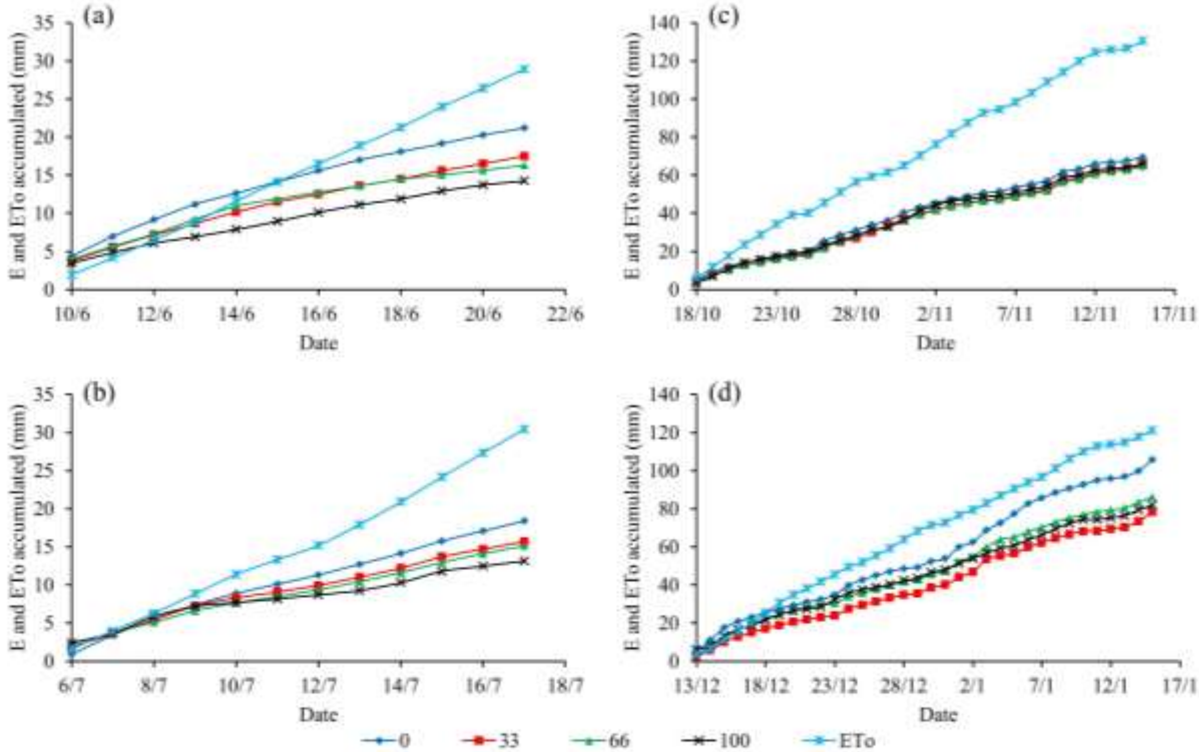

Figure 8. Reference evapotranspiration (ETo) and accumulated evaporation assessed during cycle 1 (a) and cycle 2 (b) in the fall/winter using soybean residue and cycle 1 (c) and cycle 2 (d) during the spring/summer under wheat residue.

Decreases were observed in the accumulated evaporation rates with an increase in the soil surface coverage by soybean residues (100%), compared to bare soil during the two cycles evaluated. 66 and 100% distributions presented smaller increments of cumulative evaporation during cycle 1, with 16.3 to 14.3 mm compared to 21.2 and 17.5 mm from the bare soil treatment and treatment of 33%, respectively (Figure 8a). The cycle 2 showed accumulated evaporation values close to treatments of 33 and 66%, whose values were 15.7 and 15.1 mm, respectively. The 100% treatment presented the lowest cumulative evaporation with 13.2 mm compared to 18.4 mm from treatment of bare soil (Figure 8b).

Evaporation reductions due to the presence of wheat residues were visible at the end of each drying cycle during spring/summer (Figure 8c and d). However, coverage of 66% presented a smaller increment of cumulative evaporation during cycle 1, with 64.9 mm compared to bare soil. The coverage treatments of 33 and 100% had lower results of accumulated evaporation with 78.4 and 81.90 mm compared to 105.8 mm from bare soil treatment. The values of cumulative ETo were 130.43 and 121.13 mm, which resulted in a higher evaporative demand compared to the fall/winter. The different uniformity distribution were determinants before the 4th day after soil wetting and further this period observed a similarity among treatments and amount of water lost.

Figure 9 shows decreased evaporation in 17, 23, and 33% for the distribution of soybean residue of 33, 66, and 100% during the cycle 1 of the fall/winter season compared to bare soil. In cycle 2, second-degree polynomial model showed evaporation reductions of 15, 18, and 29% for residues distributions of 33, 66 and 100%, respectively.

In spring/summer cycle 1, reductions in evaporation were 5, 7, and 5% for soil coverage of 33, 66, and 100% compared to bare soil (Figure 9b). While cycle 2 demonstrated a greater evaporation reductions, with values of 26, 18, and 23% for soil coverage of 33, 66, and 100% compared to bare soil treatment. The evaporation reductions were smaller in cycle 2 to treatment of 33% of residue distribution with the consequence of a possible action of winds and rainfall recorded during the study period (197 mm).

Conclusion

The results of this study showed that significant evaporation decreases with an increasing amount of crop residues, mainly at treatments 4 and 6 t ha^{-1} with

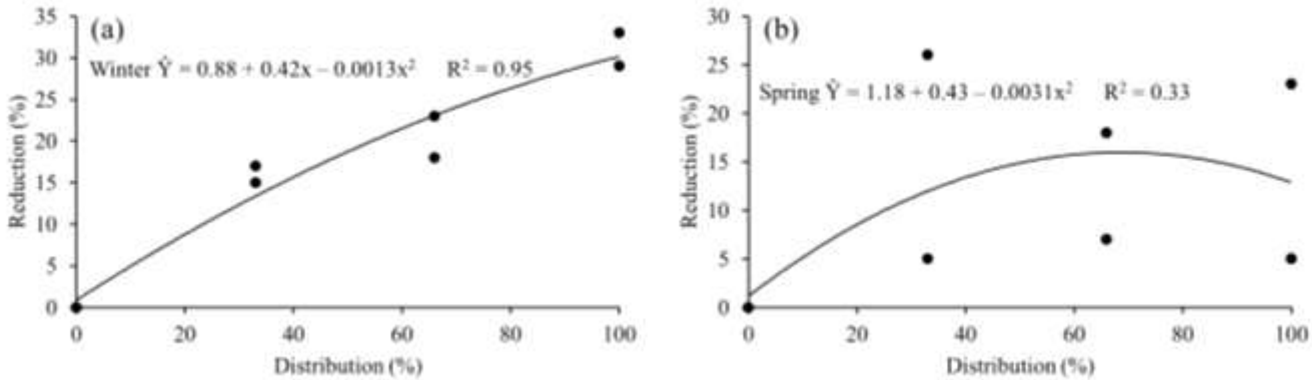

Figure 9. Reduction of evaporation due to the distribution of crop residues at the end of two cycles of drying during the fall/winter under soybean residue (a) and spring/summer under wheat waste (b).

reductions between 20 and 43%, respectively. Soil water evaporation reduced with the uniform distribution of crop residues over the soil at rates of 33 and 29% compared to the bare soil. Soil water evaporation decreased as the percentage of coverage for the fall/winter increased. However, the same decrease was not observed during spring/summer period. The appropriate amount and distribution of crop residue minimize soil water evaporation and promote soil water retention, which makes water available to plants over a longer period of time.

Conflict of Interests

The authors have not declared any conflict of interest.

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Determining and modeling the physical, thermal and aerodynamic properties of Pinto beans with different water contents

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The present study aimed to determine and model the physical (orthogonal axes, circularity, sphericity and apparent specific mass), thermal (thermal conductivity, specific heat and thermal diffusivity) and aerodynamic properties (thermal experimental speed) of beans grains with different water contents. BRS cultivar were used as test crop and properties were investigated with seven water contents (32.9; 28.1; 24.9; 21.9; 18.9; 16.2; 13.6% dry base- d.b.). After data collection, mathematical models were set as experimental data. At the moment of choosing the best model, the following were taken into account: the adjusted coefficient of determination (R^2) and average relative error (P). The outcome analysis showed that the orthogonal axes and beans grain circularity are directly proportional to water content reduction. Apparent specific mass decreased and sphericity remained constant, with increase in water content. Thermal conductivity, specific heat and thermal diffusivity decreased by 22.7; 12.7; 14.3%, respectively, when water content decreased from 32.9 to 13.6% d.b. The experimental terminal speed was increased by 15.3% when water content increased.

Key words: Size and shape, thermal conductivity, terminal speed, *Phaseolus vulgaris*.

INTRODUCTION

Beans (*Phaseolus vulgaris* L.) is a vegetable species from Fabaceae family, which is extremely important as human feed, easy to find and an important source of protein, minerals, vitamins and phenolic compounds (Díaz et al., 2010). Its production and consumption are observed mainly in South America, The Caribbean, Central America and Africa (Luna-Vital et al., 2015), consisting of one of the most widely harvested crops in Brazil and the world (Zucareli et al., 2015).

The beanstalk is cultivated in various Brazilian regions

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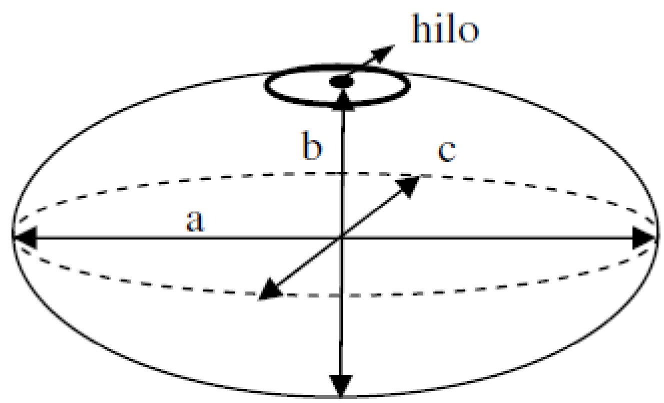

Figure 1. Schematic drawing of a bean grain with its characteristic dimensions.

with different handling types and weather conditions, favoring the deployment of new and more resistant cultivars and with desirable features to fit the final consumer (Pereira et al., 2009). Brazil is one of the main worldwide producers of this crop, with 3,182.7 thousand tons produced during the harvest of 15/16, and it is one of the major foods which follow the Brazilian basic consumption (CONAB, 2016).

The production of grain with high quality demands among other recommendations that the product is harvested safely and beforehand, aiming to decrease losses which occur in the field by insect and microorganism attack. This way, due to a high content of humidity of beans, after harvest, it is essential that the grain is dried, so its storage could be extended (Doymaz et al., 2015).

In post-harvest phase for beans, drying is the most used process to assure its quality and stability, because the decrease in water content diminishes biologic activity and the chemical and physical changes that occur within the grains throughout storage period (Resende et al., 2008). Because of this, there is a necessity of gathering information regarding physical, thermal and aerodynamic properties which are of utmost importance to aid post-harvest process, besides delivering a group of data for engineers and devisors, which will be the basis for machinery designing, structures, control processes and deliver a better efficiency of a piece of equipment or operation (Araujo et al., 2014).

The adjustment of mathematical models to experimental data is essential to forecast and simulate grain behavior, which are submitted to a certain process. Therefore, the use of mathematical models during drying, contributes to the execution of projects and equipment dimensioning, as well as the comprehension of related processes (Corrêa et al., 2011).

Regarding the aforementioned, this study aimed to determine the physical, thermal and aerodynamic properties of pinto beans grains in different water contents during drying process, in such a way as to contribute to their suitable processing.

MATERIALS AND METHODS

The experiments were performed in Laboratory of Drying and Storage of Vegetable Products of the State University of Goiás, Anápolis, GO. The geographical coordinates of the county is at latitude 16º 19’ 43” south and longitude 48° 57’ 12” west, in the State of Goias.

The pinto beans grains (*Phaseolus vulgaris* L.), cultivar BRS Estilo, produced by Embrapa rice and beans, located in Santo Antonio de Goias, were used in this study. The grains were stored with initial water content at 32.9% dry base (d.b.), polyethylene bags and stored in a freezer at 8°C until the beginning of experiments. The initial water content was determined by the standard hothouse method, at temperature of 105 ± 3°C, during 24 h, with three replications (BRASIL, 2009).

Samples of approximately 0.8 kg of grain were put into nets, and taken to a hothouse with forced air circulation, at constant temperature of 35 ± 1°C. The reduction in water content throughout drying was followed by gravimetric method, with the aid of an analytical scale with 0.01 g precision. The grains were dried until they have reached the following water content (28.1; 24.9; 21.9; 18.9; 16.2 and 13.6% d.b.). For each water content obtained, the product was homogenized and the physical, thermal and aerodynamic properties were determined.

Physical properties

To determine the beans grain size, considered as oblate spheroids, the dimensions of the orthogonal axes were measured (length (a), width (b) and density (c)), (Figure 1), for this determination, three 50-grain samples were used for each analyzed water content, with the aim of a digital equipment with precision 0.01 mm (Siqueira et al., 2012a; Araujo et al., 2014).

Table 1. Averages and deviations from the values of the orthogonal axes (length (a), width (b) and density (c)), apparent specific mass, sphericity and grain circularity form Pinto beans, cultivar BRS Estilo, in different water contents.

Water content (%d.b.)	Axis a (10^{-3} m)	Axis b (10^{-3} m)	Axis c (10^{-3} m)	Specific Mass (Kg m^{-3})	Sphericity (%)	Circularity (%)
32.9	10.96±0.12	7.02±0.08	5.39±0.08	729.2±10.8	68.06±0.18	64.06±0.03
28.1	10.74±0.27	6.81±0.10	5.03±0.15	758.8±4.1	66.69±0.22	63.36±0.75
25.0	10.53±0.24	6.70±0.12	5.06±0.11	768.4±3.3	67.42±0.90	63.69±1.01
21.9	10.38±0.06	6.57±0.08	5.20±0.08	769.6±2.2	68.18±0.37	63.29±0.47
19.0	10.11±0.08	6.34±0.05	5.08±0.04	788.8±4.4	68.03±0.13	62.64±0.47
16.3	10.18±0.23	6.44±0.15	5.00±0.16	790.8±4.8	67.72±0.25	63.22±0.08
13.6	10.03±0.27	6.29±0.14	5.04±0.12	814.0±5.5	68.03±0.17	62.72±0.29

The form for beans grain was determined, in three 50-grain repetitions for each water content, with sphericity estimated from values retrieved from the measures of the orthogonal axes, according to the following equation suggested by Mohsenin (1980):

$$S = \frac{(a.b.c)1/3}{a}.100 \quad (1)$$

Where, S = sphericity, %; a = measure of the greater axis, meter (m); b = measure from the normal axis to a, m; c = measure from the normal axis to a and b, m.

Circularity of beans grain was estimated by Equation 2, considering the natural resting position of the grains.

$$C = \frac{di}{dc}.100 \quad (2)$$

Where, C = circularity, %; di = diameter of the largest inscribed circle (b axis), meter (m); and
dc = diameter of the smallest circumscribed circle (a axis), m.
Determination of the apparent specific mass (ρ_{ap}), expressed in kg m^{-3}, was performed in five replications for each water content, using a hectoliter scale, with capacity of $\frac{1}{4}$ L.

Thermal properties

To determine thermal properties, the beans grains were initially removed from the freezer for six hours, so the temperature could reach balance with room temperature. Thermal properties were determined in 5 replications for each water content. Samples were homogenized and put into a beaker. Afterwards, the equipment, KD2-PRO was used, with a probe of parallel rods. The probe was introduced in the middle of the grain sample and after 10 min, the results for conductivity, thermal diffusion and specific heat were obtained.

Aerodynamic properties

To determine the experimental terminal speed of the beans grains, the equipment used was composed of a centrifugal fan, connected to a transparent acrylic tube, with diameter of 0.15 and 2 m of length. At 1 m from the surface part, a perforated screen was set, so that the product could be placed and at 1.75 m a crosslinker was connected, so that the distribution of air speed into the transversal section of the tube could be uniform. The fan was propelled by a three-phase engine of 0.735 Kw and flow control of air was performed by a frequency inverter.

The terminal experimental speed was determined with six replications for each water content. In the central part of the perforated screen, approximately 50 g of beans was placed, right after the equipment was set up to the moment the air flow started the process of fluctuation of the product. At this moment, a reading was performed for air speed, through a digital anemometer, placed at the surface and central part of the acrylic cylinder.

For the experimental data of the physical, thermal and aerodynamic properties of the pinto beans, cultivar BRS Estilo, linear regression equations and polynomial of second grade were set, using STATISTICA 12.0 software. For the choice of the best model, the magnitude of the adjusted determination coefficient (R^2) and relative error (P) was considered (Equation 3).

$$P = \frac{100}{n}\sum_{i=1}^{n}\frac{|Y - Y_0|}{Y} \quad (3)$$

Where: Y is the value observed experimentally; Y_0 is the value calculated by the model; n is the number of experimental observations.

RESULTS AND DISCUSSION

Physical properties

In Table 1, the average values and the deviation from orthogonal axes (a, b, c), specific mass, apparent specific mass and grain circularity from Pinto beans, cultivar BRS Estilo, in different water contents are depicted.

According to Table 1, a decrease of 8.49, 10.39 and 6.49% for axis length (a axis), width (b axis) and density (c axis) can be observed for beans grains, respectively, in relation to its initial dimensions, with water content reduction of 32.89 up to 13.62 (%d.b.). This way, it can be verified that beans grains presented disuniform

Table 2. Adjusted equation, determination coefficients (R^2, decimal), relative average errors (P, %), for the analyzed physical properties, in the different water contents for the pinto beans, cultivar BRS Estilo.

Propriedades Físicas	Modelos	R²	P (%)
Apparent Specific Mass	ME= 861.4-3.89*U	0.96	3.15
Axis (a)	Axis (a)= 9.30+0.05*U	0.96	5.05
Axis (b)	Axis (b)=5.74+0.04*U	0.94	5.06
Axis (c)	Axis (c)=4.81+0.01*U	0.54	5.18
Sphericity	E=70.29-0.21*U+0.004*U²	0.37	4.90
Circularity	C=62.55+0.001*U+0.001*U²	0.72	4.89

variations in the various axes, as verified in other studies (Siqueira et al., 2012b; Oliveira et al., 2014; Ren et al., 2014; Izli, 2015). From the determination of these variants of the product with water content reduction, the work performed by drier devisors is optimized, and it is feasible for them to enhance the drying system, taking into account factors such as air flow direction, product movement into drier, among other parameters and related processes (Araujo et al., 2015).

Also, in Table 1, one can verify that circularity is directly proportional to water content, with a reduction of 2.1% with a variation of the initial water content towards the end. Jesus et al. (2013) observed a similar behavior working with Pontal beans cultivar. This tendency of reduction in circularity and water content was observed by Isik and Unal (2011) with beans grains; Goneli et al. (2011) with castor; Araujo et al. (2015) with peanuts; Izli (2015) with Kenaf seeds. Now, other authors stated that the increase in water content resulted in a decrease in this feature as in Lanaro et al. (2011) and Resende et al. (2005) with beans. According to Araujo et al. (2014), with the fact that sphericity and circularity maintained their values under 80%, the inability of classification of these grains into spherical and round, apart from the water content presented is evident.

Regarding apparent specific mass, it is possible to notice an increase of 10.44%, while the water content in beans grains decreased. According to Ribeiro et al. (2005), this increase is observed for the majority of farm products, for porosity decreases when water content diminishes, independent from which methodology was used. The same behavior was observed for various products, such as: crambe fruit, analyzed by Costa et al. (2012); lentil seeds, investigated by Amim et al. (2004); beans grains, observed by Jesus et al. (2013), Oliveira Neto et al. (2012), Lanaro et al. (2011), Isik and Unal, (2011), Resende et al. (2005, 2008); soy grains, investigated by Ribeiro et al. (2005). This is contrary to results found by Siqueira et al. (2012c) for jathropa seeds, where the decrease in apparent specific mass was observed with water content reduction. The reduction of apparent specific mass of beans with the increase in water content in the grains shows that the increase of mass in the sample in function of increase in the mass of water was proportionally smaller than its volumetric expansion (Sologubik et al., 2013). As reported by Botelho et al. (2015), specific mass is a physical feature that is frequently used to evaluate mass quality of grains, in a way that, normally, for specific water content, the greater is its magnitude, the better is product quality.

In Table 2, the statistic parameters and adjusted models used for the determination of physical properties are found, in the various water contents, for Pinto beans, cultivar BRS Estilo.

According to Table 2, in relation to the apparent specific mass, axis (a) and (b), the models presented themselves appropriate to estimate these physical properties in the beans grains, featuring a high determination coefficient (R^2) and low relative average error (P). For the model of apparent specific mass, this negative linear relation existing between it and the water content was also found by other researchers who worked with grains (Isik and Unal, 2011; Barnwal et al., 2012; Sologubik et al., 2013; Sharanagat and Goswami, 2014).

Regarding axis (c), sphericity and circularity, the models did not present a high determination coefficient (R^2), not having a good adjustment to experimental data when this parameter is analyzed, however there has been a low outcome for average relative error (P). According to Segundo Madamba et al. (1996), a parameter alone is not a good criterion for model selection, for this reason, the relative average error (P) was chosen as a main selection parameter. According to Mohapatra and Rao (2005), the relative average error values below 10% are recommended for model selection. For all studied variables, these models presented themselves predictable taking into account the relative average error (P).

Thermal properties

In Table 3, the average values for thermal conductivity, specific heat and thermal diffusivity for Pinto Beans cultivar BRS Estilo, are depicted for different water contents, as well as their respective deviations.

It can be verified, according to Table 2, that thermal conductivity, specific heat and thermal diffusivity decreased by 22.7; 12.7; 14.3%, respectively, alongside water content drop-off from 32.9 to 13.6% d.b. The same behaviors were also observed by Legrand et al. (2007)

Table 3. Averages and deviations for values of thermal conductivity, specific heat and thermal diffusivity for Pinto Beans, cultivar BRS Estilo in different water contents.

Water content (% d.b.)	Thermal conductivity ($W\ m^{-1}\ ºC^{-1}$)	Específic heat ($MJ\ m^{-3}K^{-1}$)	Thermal diffusivity ($mm^2\ s^{-1}$)
32.9	0.2698±0.02	1.97±0.16	0.14±0.010
28.1	0.2350±0.03	1.61±0.19	0.15±0.008
25.0	0.2572±0.05	1.91±0.29	0.14±0.018
21.9	0.2304±0.03	1.73±0.22	0.13±0.003
19.0	0.2136±0.06	1.84±0.47	0.12±0.008
16.3	0.1982±0.02	1.73±0.14	0.12±0.009
13.6	0.2084±0.03	1.72±0.22	0.12±0.007

Table 4. Adjusted equation, determination coefficients (R^2, decimal), relative average errors (P, %) in the analyzed thermal properties, for different water contents, from Pinto beans, cultivar BRS Estilo.

Thermal properties	Equations	R^2	P (%)
Thermal conductivity	K= 0.150+0.004*U	0.91	7.68
Specific heat	C= (1.923-0.021)*U+0.001*U²	0.20	7.31
Thermal Diffusivity	D= 0.095+0.001*U	0.83	5.18

on Red beans; Shrestha and Baik (2010) on saponaria vaccaria seeds and Yu et al. (2015) on canola seeds.

Thermal conductivity and specific heat presented the same tendency of other products, such as: quinoa grain (Nunes, 2009); wheat grain (Ribeiro et al., 2007); corn grain (Andrade et al., 2004); millet and birdseed grain (Corrêa et al., 2004); soy grain (Ito, 2003); cherry coffee (Borém et al., 2002). The fact that thermal conductivity presents a higher average value for a higher water content, is directly associated with the increase in porosity, once water content in the product increases, because, according to Incropera and Witt (1996), thermal conductivity of a material is the measure of its capacity to conduct heat; for foods, it depends on, mainly, of composition, but also of the presence of empty spaces and its homogeneity. Now specific heat is essential to determine the quantity of energy required in the heating and quenching processes of the foods, which by definition, is related to heat energy needed to heat up the samples up to a desirable temperature (Yu et al., 2015).

The behavior observed for thermal diffusivity, corroborates with what was described by Borges et al. (2009), for soy grain. It has been observed that as water content decreases, the value for thermal diffusivity diminishes. The data found in this study for thermal diffusivity, differ from the ones observed by Corrêa et al. (2004) for millet and birdseed; Ribeiro et al. (2007) for wheat grain and Jian et al. (2013) with canola, in which thermal diffusivity increased with water content decrease in the grains. In other works, a great variant in thermal diffusivity values for the mass of different variety of grains, in function of water content can be verified. Ribeiro et al. (2007) verified that various factors influence heat quantity that goes through granular mass, this way, thermal diffusivity values can vary among products and varieties due to, mainly, its composition, specific mass, porosity and water content., the statistical parameters and the adjusted equations used in the determination of thermal properties, in the various water contents for Pinto beans, cultivar BRS Estilo is shown in Table 4.

In other works, a linear relation is reported between the property of specific heat and water content; however, this was not observed in this study, presenting a non-linear relation, which corroborates with what was observed by Razavi and Taghizadeh (2007), for pistachio grain. In relation to specific heat, the determination coefficient (R^2) and (P) were respectively 0.20 and 7.31. For all studied variables, these models presented themselves predictable, taking into account the relative average error (P).

Aerodynamic properties

In Table 5, the averages and standard deviations of the values for terminal experimental speed, for different water contents for Pinto beans, cultivar BRS Estilo is shown.

One can notice the increase of 15.3% in experimental terminal speed in function of the increase in water content. The same tendency was found for quinoa grain, observed by Nunes (2009); beans grain, observed by Isik and Unal (2011); Gharibzahedi et al. (2011) working with castor; Shirkole et al. (2011) with soy; Yilmaz et al. (2012) with sesame; Izli (2015) with Kenaf seeds. This is the behavior observed for the majority of the grains, once the increase in terminal speed with water content increment within the break in the study can be attributed

Table 5. Averages and deviations of the values of terminal experimental speeds, for Pinto beans, cultivar BRS Estilo, for studied water contents.

Water content (% d.b.)	Terminal Speed (m s^{-1})
32.9	4.64±0.04
28.1	4.18±0.06
25.0	4.29±0.03
21.9	4.27±0.02
19.0	4.11±0.11
16.3	4.14±0.05
13.6	3.93±0.09

Table 6. Adjusted equation, determination coefficients (R^2, decimal), relative average error (P, %) for experimental terminal speed, in different water contents for Pinto beans, cultivar BRS Estilo.

Aerdynamic property	Equation	R^2	P (%)
Terminal speed	Vt= 3.59+0.03*U	0.83	3.34

to the increase in the grain mass per unit of frontal area submitted to air flow.

One can say that, terminal speed is influenced by product shape, water content, size, orientation, viscosity within, and by specific masses of the particles and of the fluid (Treto, 2012). Other reason for this increase in the experimental terminal speed with the increase in water content is that the drag force is affected by water content of the particles (Ahmadi and Siahsar, 2011).

In Table 6, there are statistical parameters and adjusted equation from experimental terminal speed, for the various water contents of the Pinto beans, cultivar BRS Estilo.

It is shown in Table 6 that the linear model, adjusted itself properly to the data of the experimental terminal speed, with a good determination coefficient (R^2), and low relative average error (P), below 10%, the same tendency was found by other authors working with other grains, such as the ones observed by Ahmadi and Siahsar (2011) and Izli (2015).

Conclusions

According to the outcomes and under the conditions in which this study was developed, it can be concluded that:

1. Length (axis a), width (axis b), dimension (axis c), circularity, thermal conductivity, specific heat, thermal diffusivity and experimental terminal speed of the beans grain, are directly proportional to water content.
2. Sphericity was kept practically unchanged with the variation in water content of the grains.
3. Apparent specific mass is inversely proportional to water content in the grains.

Conflict of Interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Analysis of trend in agricultural services received by farmers in Benue State, Nigeria

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The study was carried out to assess trend in agricultural services received by farmers in Benue State, Nigeria. The three agricultural zones in the state, twelve blocks, thirty cells and four hundred and thirty two farmers constituted the samples for the study. Data were analyzed with percentage and mean score while some were presented in charts. Findings revealed that majority (86.8%) of the respondents were males, married (89.6%) with a mean household size of 8 persons and mean age of about 48 years, respectively. On average, they had about 20 years of farming experience, owned and cultivated 4 and 3 hectares of land, respectively. Extension visit was agricultural service that was relatively enjoyed by the respondents. The study advocated for private sector investment in agriculture especially in provision of farm credit and other crucial agricultural services to farmers in order to increase productivity and output.

Key words: Agricultural services, farmers, agricultural inputs, Benue State.

INTRODUCTION

Smallholder farmers constitute majority of farmers producing over 80% of the food supply in developing countries (The UK Hunger Alliance, 2013); but they depend on a large extent on external inputs and services. Their reliance on these external provisions is as a result of their lack of sufficient access to inputs (seeds, fertilizers, planting materials, etc.), services, credit (African Smallholder Framers Group (ASFG), 2011), livestock, financial capital, and other productive assets, such as land and water. Farmers access to productive inputs and services are critical to increased agricultural productivity. Therefore, helping small-scale farmers improve their level of living which is critically important not only for the farming families themselves, but for society as a whole (FAO, 1994).

In sub-Saharan Africa, the need to improve agricultural services and infrastructure provision has resulted in recent initiatives, including: the Comprehensive African Agricultural Development Programme (CAADP), which calls for 6% agricultural growth rates; the Maputo Declaration, which calls for 10% of the total public spending to be used for agriculture; and the 2006 Abuja Declaration, which calls for a substantial increase in fertilizer use (Akramov, 2009).

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In Nigeria, agricultural support services are mainly provided by the public sector mainly through the establishment of institutional support in the form of agricultural research, extension, commodity marketing, input supply, and land use legislation. The private sector also contributes to agriculture support services through investment in financing, sponsorship of research and breakthrough on agricultural issues in universities, capacity building for farmers, and provision of financing to farm businesses. On the other hand, international governmental and non-governmental agencies including the World Bank, Food and Agricultural Organization of the United Nations, etc., also contribute through on-farm and off-farm support in form of finance, input supply, and strengthening of technical capacity of other support institutions, etc. (Eze et al., 2010). There is therefore a general commitment of government, private sector and donor agencies towards the provision of agricultural services to small-scale farmers. In view of these, it is expected that over the years, farmers' access to agricultural service should improve with the concomitant improvement in their production. This study was a survey of the trend on these services that farmers in the area have received for the period before year 2007, 2007, 2008, 2009, and 2010.

Purpose of the study

The overall purpose of the study was to analyze the trend in agricultural services received by farmers in Benue State, Nigeria. Specifically, the study sought to:

i. Describe the socio-economic characteristics of respondents,
ii. Determine the trend in agricultural services received by farmers in the area.

MATERIALS AND METHODS

The study was carried out in Benue State, Nigeria. The state is referred to as the food basket of Nigeria, because of the abundance agricultural resources which invariably attracts farmers from other areas. Proportionate sampling technique was used to select twenty five percent of blocks in each of the three agricultural zones in the state; hence, five, three and four blocks were selected from zones A, B, and C, respectively giving a total of twelve blocks. Three cells were randomly selected from each of the selected blocks giving a total of 36 cells. Twelve farming households were selected from each cell. This gave a total sample size of four hundred and thirty two households. Data for the study were collected using interview schedule. Data on the socio-economic characteristics of respondents were collected by asking respondents to indicate their age in years, sex (either male or female), number of people in their household, farming experience in years, and whether they belonged to any social organization. Data on agricultural services received were collected by asking respondents to indicate the agricultural services they received during the period under study (that is, before 2007, 2007, 2008, 2009, and 2010). Agricultural training, loans from public and private sectors were some of these agricultural services in the list. Data were analyzed with percentage, while some were further presented in bar charts.

RESULTS AND DISCUSSION

Socio-economic characteristics of respondents

Data in Table 1 show that majority (86.8%) of the farmers were male, majority (89.6%) were married, and the mean age of the respondents was 47.9 years. Greater proportion (30.1%) had secondary education. This shows that the respondents had some level of formal education which could enhance their ability to participate in programmes aimed at providing agricultural services to farmers in the area. The mean household size was 9 persons, while mean farming experience of the respondents was 19.7 years. Generally, the farmers had long years of farming experience. Greater proportion (55.0%) of the respondents belonged to 1 or 2 social organizations, 29.4% did not belong to any organization, while 15.6% belonged to 3 or 4 organizations. This implies that farmers in the area belonged to one or more social organizations. According to Ekong (2003), rural dwellers belong to organizations that help in satisfying their innate need for belonging and affiliation and in solving their problems through collective efforts. The existence of these social organizations is a veritable opportunity for government and other development agencies interested in providing agricultural services to reach a large number of farmers in the area. However, farmers in the area belonged to trading/artisan union more than other organizations including farmers' cooperatives. This may suggest interest of these farmers on trading and artisanship organizations more than farmers' organizations. This calls for a need to encourage formation of more farmers' groups in the area which will enhance their ability to obtain available agricultural services.

Agricultural services received by the respondents before 2007 to 2010

Extension visit

Figure 1 shows that about 50% of the respondents had extension visits before 2007 with decline (49%) in 2007 and increase (59% and 64%) in 2008 and 2009, respectively and another decline (60%) in 2010. Findings reveal that respondents had more extension contact in 2010 than before 2007 irrespective of high farmer-extension agent ratio being experienced in countries like Nigeria especially as years go on due to poor remuneration and consequent high turnover as well as labour drift in the profession. This scenario suggests that there will be improved agricultural productivity among farmers since experiences with extension programmes

Table 1. Percentage distribution of the respondents according to their socio-economic characteristics (Field Survey Novovember, 2011).

Characteristic	Percentage (n=432)	Mean
Age (years)		
21-30	4.9	-
31-40	22.4	47.9
41-50	39.6	-
51-60	22.5	-
>60	10.6	-
Sex		
Male	86.8	-
Female	13.2	-
Marital status		
Married	89.6	-
Single	5.1	-
Separated	0.9	-
Widowed	4.4	-
Educational qualification		
No formal education	18.3	-
Primary education	28.9	-
Secondary education	30.1	-
OND/NCE	16.0	-
HND/degree	3.9	-
Higher degree	2.8	-
Household size		
1-5	29.6	-
6-10	47.5	-
11-15	13.9	8
16 and above	9.4	-
Farming experience		
1-10	26.6	-
11-20	39.4	-
21-30	19.4	-
>30	14.6	19.7
Organizational membership		
Farmers cooperatives	50.5	-
Family/Community organization	22.4	-
Religious organization	32.9	-
Trade /artisan union	55.1	-
Political group	1.2	-

*Multiple responses.

show positive impact on productivity and incomes (Global Forum for Rural Advisory Services (GFRAS), 2012).

Subsidy from government

Figure 2 shows unsteady trend in the proportion of farmers that received subsidy from the government during the period under study. About 18% of them received subsidies from government before 2007, which rose to 21% in 2007, declined to 19% in 2008, rose again to 25% in 2009 and declined again to 22% in 2010. The findings show that proportion of farmers that received subsidies from government was generally low hence

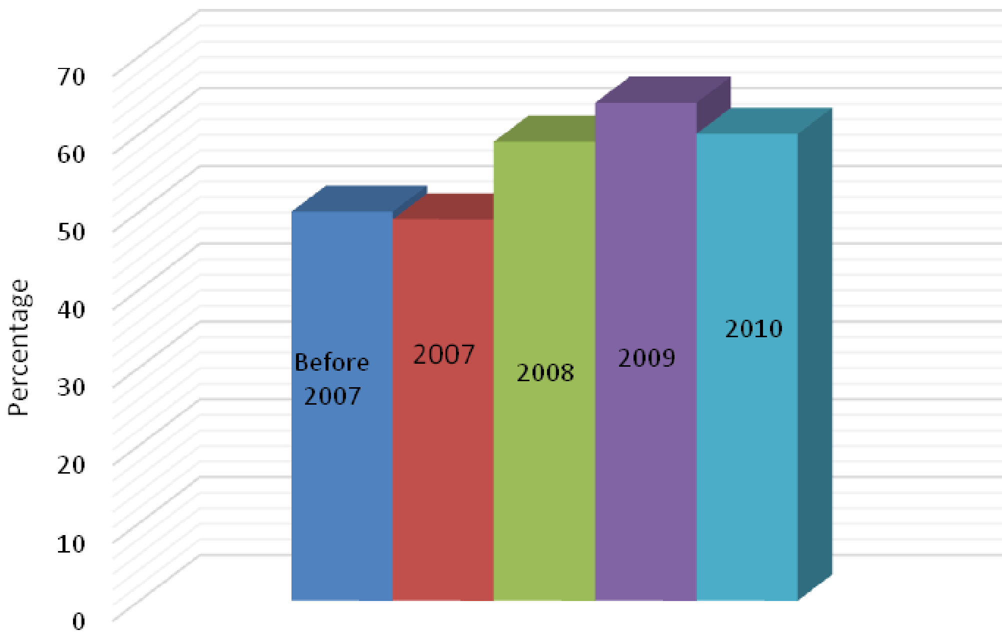

Figure 1. Proportion of farmers that had extension visit.

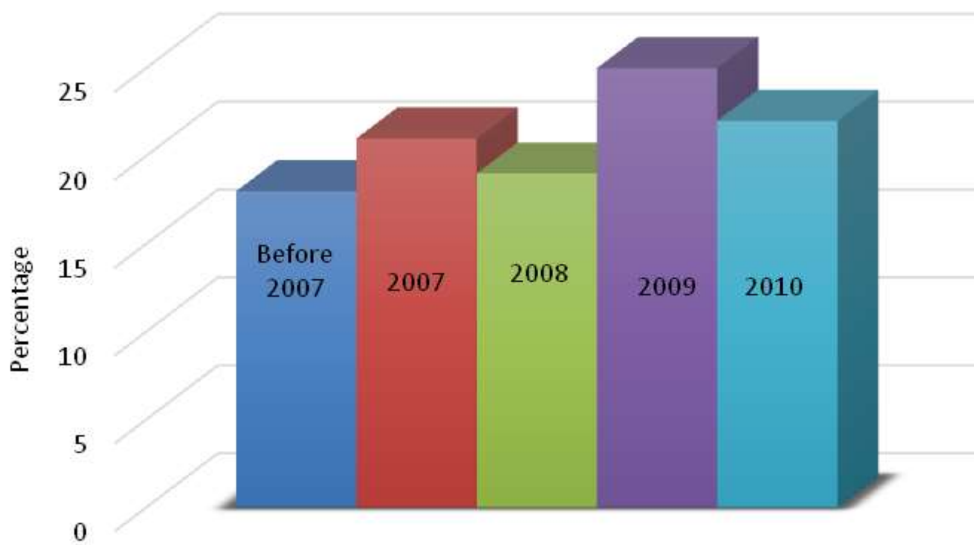

Figure 2. Proportion of farmers that received subsidy from government.

contradicting the understanding that policy of agricultural subsidy is now being followed in some countries of Africa like Tanzania, Nigeria, and Zambia (INICA, 2012).

Loan from public sector

Only 9% of the respondents received loans from public sector before 2007 which decreased to 7% in 2007, but increased to 9 and 13% in 2008 and 2009, respectively and rose again to 12% in 2010 (Figure 3).

Generally, loan from public sector is not always available and when available the targeted beneficiaries like farmers encounter difficulties in securing it due to corruption and lack of collateral. Other factors that may have constrained them from securing loan from this sector may be bureaucracy involved in procurement of loan and inability of majority of the beneficiaries to repay their loan

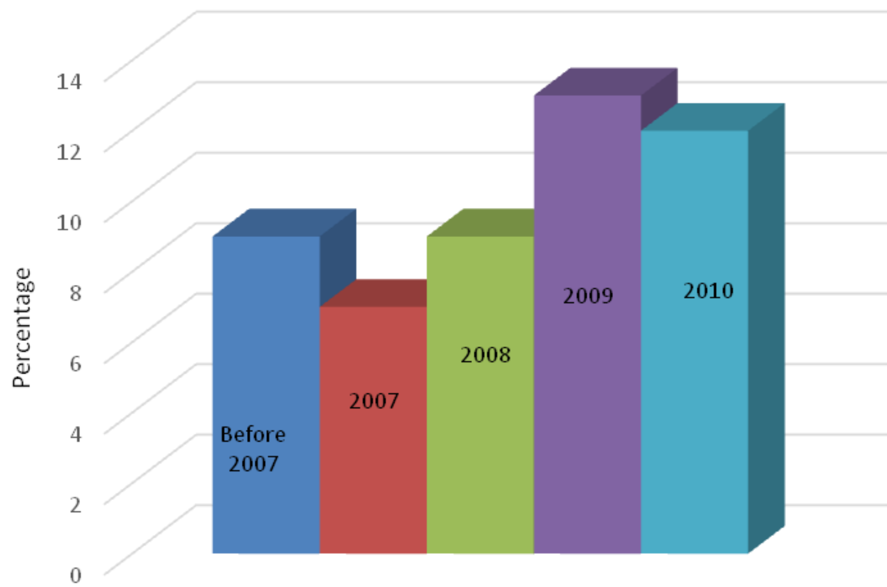

Figure 3. Proportion of farmers that received loans from public sector.

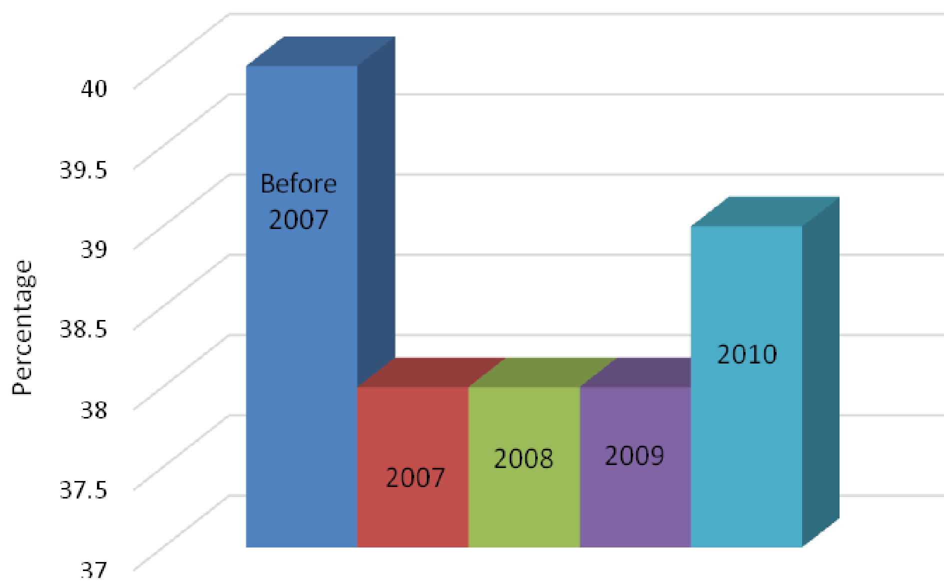

Figure 4. Proportion of farmers that received loans from private sector

on time (Aneke, 2007).

Loan from private sector

It is evident in Figure 4 that 40% of the respondents received loan from private sector before 2007 while the proportion that received it declined to 38% each in 2007, 2008 and 2009, but slightly increased to 39% in 2010.

Generally, the proportion of respondents that received loan from private sector was also low, but was greater than those who sourced from public sector in all the years considered irrespective of the fact that private sector banks interest rates are slightly higher as compared to public sector banks (Bank, 2011). This point to the role private sector will play in boosting agriculture if their activities are properly incorporated and harnessed toward agricultural growth. The finding also supports the fact that non-profit and for-profit private companies were found to have minimal involvement in agricultural research and

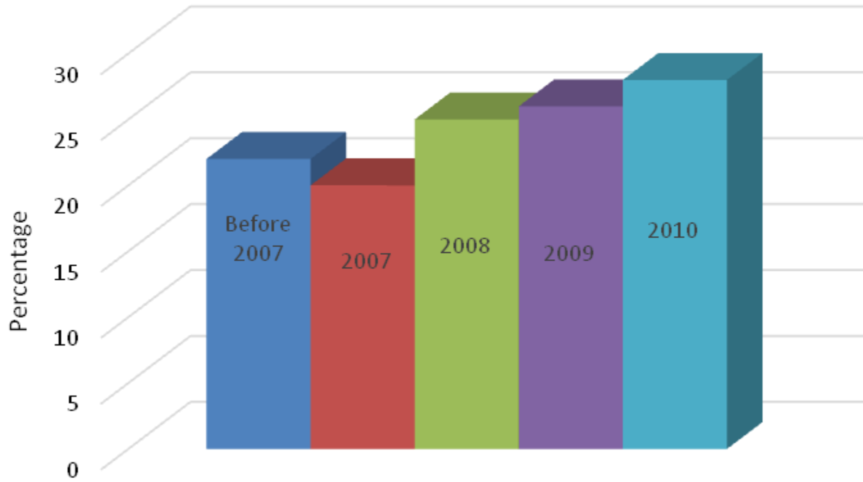

Figure 5. Proportion of farmers that participated in agricultural training/workshop.

development in Nigeria (Flaherty et al., 2010).

Agricultural training and workshop

Figure 5 indicates that only 22% of the farmers participated in agricultural training and workshop before 2007 which declined (20%) in 2007 and increased (25, 26, and 28%) in 2008, 2009, and 2010, respectively. Ibitoye et al. (2013) stated that greater productivity could be achieved through improved knowledge and skills when farmers are exposed to proper trainings. Although the participation in agricultural training and workshop by the respondents was low thus corroborating the fact that about 82% of pineapple farmers in Enugu State had no training on agricultural matters (Udoye, 2012), trend in participation of the farmers in workshop and training had slightly, but steadily increased from 2008 to 2010. This may suggest that these farmers were participating more in these activities in recent time and if this trend is consolidated more farmers will participate in agricultural training and workshop in near future and this will impact positively on their productivity.

Conclusion

Based on the findings of this study, it can be deduced that the farmers were relatively young, had formal education, and large household size which when harnessed properly will provide labour for engagement in agricultural and non-agricultural activities. They owned large land, but did not cultivate the entire land they owned. Farmers received less agricultural services, in recent time. This may invariably affect agricultural production and demoralize these farmers. Private sector development and investment in agriculture especially in the area of provision of credit and order services to farmers should be embarked upon. This can be done through establishment of commercial and micro-finance banks, thrift and cooperative societies, private extension organizations, etc., so that farmers can be provided with their agricultural needs and thus move into profitable farm ventures. Since, their services are often not biased, more available, efficient and timely to meet up profitable and time sensitive agricultural activities.

Government should provide more incentives and subsidies to farmers. Most importantly, they monitor the modalities for the distribution and acquisition of these services so that they can get to the right recipients that can deploy them in agricultural tasks for a healthier and richer nation.

Conflict of Interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Physical properties of an Oxisol under different planting and management systems

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The changes of soil physical and mechanical properties, arising from the traffic of machines in farming operations, have been widely studied, emphasizing the negative effects of soil compaction on crop productivity. The objective was to evaluate the physical properties of an Oxisol under different planting and management systems. A completely randomized design one-way was adopted for the collection of soil samples. The treatments consisted of four systems of planting and management (no tillage, conventional planting, area under pasture and fruit cultivation) with three replications. All samples were obtained at a depth of 0 to 0.15 m. The physical properties of the soil were: bulk density, degree of compaction, liquid limit, plastic limit and total porosity. All physical properties varied statistically (P<0.05) for the different systems of planting and management. The fruit cultivation area has demonstrated in all soil physical attributes a good quality, since over the years the accumulation of organic matter from decomposition of the leaves may have caused this better physical quality of the soil. The conventional planting and the pasture are more susceptible to erosion, principally in the first case where the soil disaggregation caused by this system can enhance the erosion of the soil. As a conclusion, the bulk density and degree of compaction has shown that the no tillage was the planting and management systems with the worst soils' physical properties.

Key words: Compaction, limits of consistency, degree of compaction, total porosity.

INTRODUCTION

Soil structure represents one of the most important soil physical properties as it is directly related to its quality, development of root system, and crop production. Changes in soil structure, caused by different soil management systems, produce important modifications in soil physical properties (Cássaro et al., 2011). The soil

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Table 1. Soil mechanics and physical characterization for different planting and management systems.

Parameter	No tillage	Conventional planting	Pasture	Fruit cultivation
Sand content (%)	42.00	49.33	45.33	40.00
Silt content (%)	24.00	25.34	27.33	22.00
Clay content (%)	34.00	25.33	27.33	38.33
Maximum dry density(Mg m^{-3})	1.583	1.590	1.571	1.483
Critical moisture for compaction (Kg Kg^{-1})	0.2471	0.2228	0.2353	0.2819

may be naturally condense, or by human action, compacted. The use of machinery and implements with soil moisture close to the plastic limit is the main factor that compact agricultural soils because the water reduces cohesion and acts as a lubricant between soil particles, allowing the particles slip and packaging when it is submitted to some kind of pressure.

Therefore, to properly manage the agricultural soils and understand the dynamics of compression, it is necessary to evaluate the limits of consistency and its relation to the present bulk density (BD), the maximum dry density (Dr) and critical moisture for compaction obtained through the Standard Proctor Test (Luciano et al., 2012). Another usual indicator to quantify and qualify the impact of the use and management in physical property of the soil is the degree of compaction (DC). This is a product of the ratio between the BD and Dr. Thus, the DC eliminates the influences of particle size distribution, mineralogy and soil organic matter, thus facilitating their use in the study and comparison of different systems of use and management of soils (Betioli Junior et al., 2012). The objective of this study was to evaluate the physical properties of a dystrophic Red Oxisol under different planting and management systems.

MATERIALS AND METHODS

The project was conducted at the experimental station of EMATER Anapolis, Goias, Brasil. The area presents the historical following of planting and management: the no tillage has been used for about 15 years with the crop rotation of soybean (summer) and winter maize; the conventional planting system is used since the area was opened to the farm in the mid-1970s, it has since been managed with two heavy disking and one leveling which is later used as a conventional seeder; the fruit cultivation was established in 1996, which are mango trees, the use of agricultural machines and implements in the area is minimal, restricted to the weeding of spontaneous vegetation; the pasture was implemented in mid-1990s and since then does not receive any kind of management, such as fertilizer or correct soil acidity, the stocking is 1.5 animals per hectare. The soil is characterized with a dystrophic Red Oxisol (EMBRAPA, 2006). A completely randomized design one-way was adopted for the collection of soil samples. The treatments consisted of four systems of planting and management (no tillage, conventional planting, are a under pasture and fruit cultivation) with three replications. Samples were taken at points with areas of approximately one square meter, removing all surface coverage. All samples were obtained at a depth of 0 to 0.15 m.

The particle size was determined by mass particles, according to Donagema et al., (2011). To determine the maximum dry density and critical moisture for compaction, a proctor test was conducted, with previously air-dried samples until achieving gravimetric moisture, following the methodology described in the NBR 7182 (ABNT, 1986). The results of the analysis of some physical and mechanical characteristics of the soil, corresponding to the average values, are show in Table 1. The bulk density (BD) was determined from undisturbed samples collected using a Uhland sampler type with 0.05 m of internal diameter and 0.05 m of tall, with an internal volume of 100 cm^3. The value of bulk density was established by the ratio between mass of dry soil in the greenhouse and its volume (Donagema et al., 2011). The determination of the degree of compaction was performed through the ratio between bulk density and maximum density obtained in the laboratory, given by Equation 1:

$$DC = \frac{BD}{Dr} \times 100 \quad (1)$$

Where:
DC - Degree of soil compaction (%);
BD - Soil density (Mg m^{-3});
Dr - Maximum dry density obtained in laboratory (Standard Proctor Test) (Mg m^{-3}).

The liquid limit was determined from the resistance power to the shear corresponding to 25 strokes necessary for the closing of fluting made on the ground, according to the methodology of Donagema et al. (2011). The plasticity limit was determined by the methodology of Donagema et al. (2011), where the minimum necessary moisture to form a rod of 3 mm diameter and 100 mm length. The total porosity (TP) of the soil was determined from the data of bulk density and particle density (Donagema et al., 2011). As Equation 2:

$$TP = \frac{100\ (PD - BD)}{PD} \quad (2)$$

Where: TP - toral porosity (%); PD - particle density (Mg m^{-3}); BD - bulky density (Mg m^{-3}).

The values obtained were subjected to analysis of variance using F test at 5% probability and when there was a significant difference between treatments, averages were compared by Tukey test at 5% probability. The software SISVAR 5.1 was used in all statistical procedures (Ferreira, 2011).

RESULTS AND DISCUSSION

The variance analysis of soils' physical properties has its

Table 2. Summary of the variance analysis of variables expressed by the mean square of physical soil properties: bulk density (BD, Mg m^{-3}), degree of compaction (DC, %), liquid limit (LL, %), plastic limit (PL, %), total porosity (TP, %).

VF	GL	BD	DC	LL	PL	TP
PMS	3	0.03359*	111.90227*	86.06630*	46.44176*	53.03159*
Residue	32	0.00746	34.0673	3.02970	1.68472	12.45867
	C.V.	6.97	7.37	4.91	4.80	6.62
	Overall average	1.24	79.19	35.47	27.03	53.28

* significant of 5% (P<0.05); C.V.: Coefficient of Variation; PMS: planting and management systems.

Table 3. Average values of bulk density (Mg m^{-3}) according to the planting and management systems.

Planting and management	Averages
No tillage	1,423 [a]
Conventional planting	1,283 [a]
Pasture	1,187 [ab]
Fruit cultivation	1,127 [b]

Means followed by the same letter do not differ on Tukey test (P>5%).

Table 4. Average values of degree of compaction (%) according to the planting and management systems.

Planting and management	Averages
No tillage	92.67 [a]
Conventional planting	80.67 [ab]
Fruit cultivation	77.76 [ab]
Pasture	76.00 [b]

Means followed by the same letter do not differ on Tukey test (P>5%).

results presented in Table 2. The results shows that all the physical properties were significantly (P<0.05) affected by the planting and management systems. The mean values of the bulk density for different planting and management systems are presented in Table 3. In the same vein, the highest average bulk density was obtained at the no tillage stage followed by conventional planting, and there is no difference between these two. The lowest average density is related to fruit cultivation, and the area under pasture showed an intermediate value. Means followed by the same letter do not differ on Tukey test (P>5%). The traffic of machines and implements can be the factor responsible for increasing bulk density at the no tillage and conventional planting (Mascara et al., 2013), for the area under pasture the cattle trampling is the main factor for the density value found (Kondo and Dias Junior, 1999). The fact that the fruit cultivation shows the lowest density occurs at low traffic of machines and implements and greater accumulation of organic matter (Clemmensen et al., 2013). The lower bulk density values found in pasture and fruit cultivation are likely due to the accumulation of organic matter over the years, as this tends to affect the physical attributes of the soil. According to Andrade et al., (2009) the accumulation of organic matter causes a decrease in density, and there is an increase in total porosity and macro porosity with the increase of the content in the soil.

The compression process occurs when there is degradation in the soil structure, resulting, reduced porosity, the ability to store water and air and water permeability (Molchanov et al., 2015). For these same authors, clays soil with a density value below 1.20 Mg m^{-3}, between 1.20 and 1.30 Mg m^{-3} and up to 1.40 Mg m^{-3} are not compressed, slightly compressed and strongly compacted, respectively. It can be observed, therefore, that the no tillage is strongly compacted. The mean values of the degree of compaction for different planting and management systems is presented in Table 4, which shows that the highest average degree of compaction is present at the no tillage system, while the lowest one is in the area under pasture. Intermediate values are present in conventional planting and fruit cultivation, respectively, and they do not differ. According to Suzuki et al. (2005), the degree of compaction (DC) necessary for a suitable growth and development of plants, for the macro porosity corresponding to 0.10 m^3 m^{-3}, would be 80% for soils with 20 to 30% of clay and 75% for soils with 30 to 70% of clay, therefore, the fruit cultivation would be above the tolerated DC, since this present 38.33% of clay (Table 1). Conventional planting and pasture area have satisfactory values of DC, as they have 25.33 and 27.33% of clay (Table 1), respectively. To Suzuki et al., (2007), the DC referring to 2.0 MPa penetration resistance - a limiting value to root growth - on Oxisol, would be 84%, thus the no tillage must be with the DC above the limiting value.

The average values of liquid limit for different planting and management systems are shown in Table 5. According to this table, the fruit cultivation has a higher value in the liquid limit, followed by no tillage. The area with pasture and conventional planting had the lowest values, respectively, and they do not differ. The liquid limit value (LL) are influenced by the clay soil, thus, the more clay greater LL. The highest average value for fruit

Table 5. Average values of liquid limit (%) according to the planting and management systems

Planting and management	Averages
Fruit cultivation	41.67 [a]
No tillage	37.30 [b]
Pasture	32.67 [c]
Conventional planting	31.60 [c]

Means followed by the same letter do not differ on Tukey test (P>5%).

Table 6. Average values of plastic limit (%) according to the planting and management systems.

Planting and management	Averages
Fruit cultivation	30.13 [a]
No tillage	28.87 [a]
Pasture	25.26 [b]
Conventional planting	25.70 [b]

Table 7. Average values of total porosity (%) according to the planting and management systems.

Planting and management	Averages
Fruit cultivation	58.75 [a]
Pasture	56.90 [ab]
Conventional planting	52.59 [b]
No tillage	48.85 [b]

Means followed by the same letter do not differ on Tukey test (P>5%).

cultivation corroborates assessments by Dias et al., (2012). Vasconcelos et al. (2010) evaluated different waste of sugarcane in consistency measures of an Oxisol, found no differences in the LL behavior, showing that it is influenced only by the soil particle size and is independent of the organic matter of the same. The liquid limit is indicative of soil conservation potential, and the higher its value will be lower susceptibility of soil to erosion (Couto, 2015). Thus, the conventional planting and the pasture are more susceptible to erosion, so the soil management practices must be consciously performed, principally in the first case where the soil disruption caused by this system can enhance the erosion of the soil. Table 6 shows the average values of plasticity limit for the different planting and management systems. In the same vein, the highest values were found for fruit cultivation and no tillage, respectively, both of which do not differ. The lowest values were for conventional planting and pasture, respectively, there is no difference between them.

The plasticity limit (PL) is also influenced by the soil granulometry, as well as the liquid limit, so the values obtained here are similar to the LL. Another factor which strongly influences the PL is the amount of organic matter present in soil. Vasconcelos et al. (2010), by evaluating different waste from sugarcane in consistency measures of an Oxisol, found differences in PL behavior when different organic residues were added into the soil. When comparing the different planting and management systems, PL data for fruit cultivation corroborate to Dias et al. (2012), mentioning the importance of increasing organic matter in the PL. The increase in organic matter is important to increase the plasticity limit values primarily in fruit cultivation area. Figueiredo et al. (2000) observed that soil moisture affecting operations with agricultural machinery is close to 90% of the plastic limit (90PL). It notes that for systems that receive greater intensity of traffic of agricultural machinery and implements the 90PL values were above the critical moisture value for compression, and the no tillage and conventional planting present value of 25.98 and 23.13%, respectively. In the case of fruit cultivation and pasture, which receive less traffic of agricultural machinery, this value was below the critical moisture for compaction, equal to 27.12 and 22.73%, respectively. Thus, an increase in the PL can cause an increase in the friability range, facilitating or causing a higher moisture clearance for operations with agricultural machinery. The average critical moisture for compaction (Table 1) was less than the value of the PL, which was also observed by Figueiredo et al. (2000) that suggest that avoids up traffic with agricultural machines when soil moisture is approximately equal to the PL, since the critical moisture for compaction is next to this humidity range. Table 7 shows the average values of total porosity for different planting and management systems.

The total porosity is influenced by bulk density, being inversely proportional to it, thus the average values of total porosity follow the reverse order of bulk density. For Carvalho et al. (2004). the highest amount of porosity in agroforestry cultivation system is possibly a reflection of the greater biological activity and its effects on soil aggregation. These same authors found similar values when compared agroforestry farming system (64.71%) with conventional planitng (54.38%) in the Cerrado Oxisol. Araujo et al. (2004) also found similar values for total porosity when compared native forest with conventional planting in an Oxisoil. The highest bulk density values directly influenced the lower total porosity values for the no tillage and conventional planting systems, values associated with higher traffic intensity of agricultural machinery and implements. The intermediate value found in the area under pasture occurs by animal trampling, corroborating with Kondo and Dias Junior (1999), which demonstrate that the cattle trampling grazing occurs mainly in the most superficial layer of soil, about 0 to 0.03 m.

Conclusion

The fruit cultivation was the planting and management systems with the best soils' physical properties. The bulk density and degree of compaction has shown that the no tillage was the planting and management systems with the worst soils' physical properties.

Conflict of Interests

The authors have not declared any conflict of interests.

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Evaluating land suitability for irrigation purpose in Abaya district, Borena zone, Ethiopia

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Assessment of land suitability for irrigation purpose is important to utilize limited resources efficiently and for the sustainable production of crops and food security of the ever increasing people in our country especially the study area. The existing small scale irrigation system in the Guangua Badiya river basin farming area has no adequate soil and land resource information and also the irrigated area is very small. Thus irrigation land suitability assessment plays an imperative role for sustainable utilization of scarce physical land resources. This study was initiated with the objective of assessing land suitability evaluation for agriculture under irrigation of the River Guangua Badiya in Abaya District of Borena Zone, Oromiya Region, Ethiopia. Watershed delineation, assessment of soil and slope parameters were the steps followed to evaluate land suitability for irrigated agriculture. To identify land suitability for irrigation purpose, the following factors such as soil type, slope, and distance from water supply (sources) were taken into account. Soil sampling spots were selected based on free and grid survey techniques and their locations were taken using Global Positioning System (GPS). Soil samples were collected and used for suitability assessment. Soil samples used as criteria for irrigation suitability analysis were pH, texture, soil depth, EC, ESP, top and sub soil stoniness. Slope suitability map of the study area was derived from digital elevation model of the area clipped from SRTM of NASA satellite with 30 m resolution by masking layer of sub catchment. Qualitative evaluation was carried out with the help of FAO land evaluation method. Result of suitability of land evaluation ratings based on the qualitative land suitability for irrigation indicated that, 9.32% (1303 ha) are highly suitable (S1), 32.5% (4558 ha) are moderately suitable (S2), 23.82% (3335 ha) marginally suitable (S3) and 34.30 (4802 ha) are not suitable (N) for surface irrigation systems. Hence, the majority of the study areas are in a range value of highly to marginally suitable for surface irrigation purpose. Due to high slope range value 4802 ha of lands are non-suitable for irrigation purpose.

Key words: Suitability, irrigation, soil properties, Guangua Badiya river.

INTRODUCTION

Background

Ethiopia is an agrarian country on which agriculture provides 47% of the gross domestic product (GDP), 80% of the employment and 60% of the export commodity (World Bank, 2011). The country depends on the rain fed agriculture with limited use of irrigation for agricultural production. It is estimated that more than 90% of the food supply in the country comes from low productivity rain-fed smallholder agriculture and hence rainfall is the single most important determinant of food supply (FDRE, 2011). Considering the fact that, production system is dominated by small-scale subsistence farming system largely based on low-input and low-output rain-fed agriculture. As the result farm output lags behind the food requirement of the fast growing population. The high dependency on rain-fed farming and erratic rainfall require alternative ways of improving agricultural production.

The need to double food production over the next two decades, water has been recognized as the most important factor for the transformation of low productive rain-fed agriculture into most effective and efficient irrigated agriculture (FAO, 1996). It is obvious that the utilization of water resources in irrigated agriculture provide supplementary and full season irrigation to overcome the effects of rainfall variability and unreliability. Hence, the solution for food insecurity could be provided by irrigation development that can lead to security by reducing variation in harvest, as well as intensification of cropping by producing more than one crop per year.

Ethiopia has immense potential in expanding irrigated agriculture. Despite its irrigation potential which is estimated to be about 3.7 million hectare, only about 190,000 ha (5.3% of the potential) is currently under irrigation, which plays insignificant role in the country's agricultural production (Negash and Seleshi, 2004). Use of land and water resources for the development of irrigation facilities could lead to substantial increase in food production in many parts of the world. Proper use of land depends on the suitability or capability of land for specific purposes (Fasina et al., 2008).

Thus, to bring food security at national as well as household level, improvement and expansion of irrigated agriculture must be seriously considered.

In developing supplementary irrigation, evaluating and assessing of the potential and suitability of the land area will provide a comprehensive and integrated economic viability and sustainability of water resource development. However, in Ethiopia, particularly in the study area this is almost ignored and any type of irrigation is practiced without proper investigation on the potential of the area for irrigation purpose. To reduce the human influence on natural resources and to identify an appropriate land use, it is essential to carry out scientific land evaluations. Such kind of analysis allows identifying the main limiting factors for the agricultural production and enables decision makers to develop crop managements able to increase the land productivity. Therefore, the main target of this study was to determine the land suitability of the study area for irrigation purpose.

MATERIALS AND METHODS

Description of the study area

The study was carried out in Guangabadiya sub catchment, in Abaya district (Figure 1). It is found in Oromia regional state (06°11' 56"- 06°25'06"Latitude and 38°06'00"Longitude). The area is located at about 430 km east of Addis Ababa. It has bimodal rain fall pattern, with annual average rain fall of 700 to 1200 mm; daily mean temperature ranges 27°C. The dominant soil type in the area is clay soil and the soils within the command area have deep effective soil depth The district has a total areas of 187134 ha of land, out of which, 60728 ha cultivated land, 45275 ha grazing land, 12404 ha forest and bush land, 62925 ha covered by Lake Abaya, and 5801 ha allotted for other activities. Abaya district has a potential of more than twelve perennial rivers include the Gelana and Gidabo and also in the area both traditional and modern irrigation systems are practiced. The area with heavily deforested, and the remaining vegetation is predominantly scattered bush, and acacia trees. The major crops grown in the area are: Maize, teff, haricot bean, groundnut, tomato, onion, potato, pepper, cabbage, coffee and enset (Abaya Woreda Agricultural Office Report, 2014).

Method of data collection

Watershed delineation: Watershed delineation was done using ArcSWAT 10 which is imbedded in ArcGIS 10. The watershed delineation showed that the Guangua Badiya river basin covers a total area of 13,998 ha (Figure 2).

Soil and slope data: Based on a preliminary soil survey, soil samples were collected from five profile and ten auger holes .The sampling points were selected using free survey techniques. Being a medium intensity soil survey one observation per 50 ha was taken as per the recommendations of (FAO, 1979). Observation sites were located according to the requirements and complexity of the soil patterns and composite soil samples were used for soil analysis. The internal properties of the soil were described by using profile pits. Profile explorations were made at five suitable sites based on drainage property of the specific location and relative position in the slope of the study area described by using soil description guideline (FAO, 1990). In characterizing the topsoil and subsoil, five profile and ten auger holes (sampling points) were collected at 0-40 and 40-80 cm depth and their geographic location recorded using hand held GPS. The main focus of the study was on existing cultivated lands. The land evaluation was determined based upon topography and soil characteristics. The topography characteristics included slope while the soil samples were analyzed for top soil texture, stoniness soil properties, salinity, pH, cation exchange capacity (CEC), exchangeable sodium percentage (ESP) organic matter (%OM) and pH were considered (Sys et al., 1991). Land slope is the most important topographical factor influencing land suitability for irrigation. To derive slope suitability map of the study area, digital elevation model of the area was clipped from SRTM of NASA satellite with 30 m resolution by masking layer of Woreda boundary.

Suitability assessment method: The FAO (1976) frame work of suitability classes was commonly used (d'Angelo et al., 2000;

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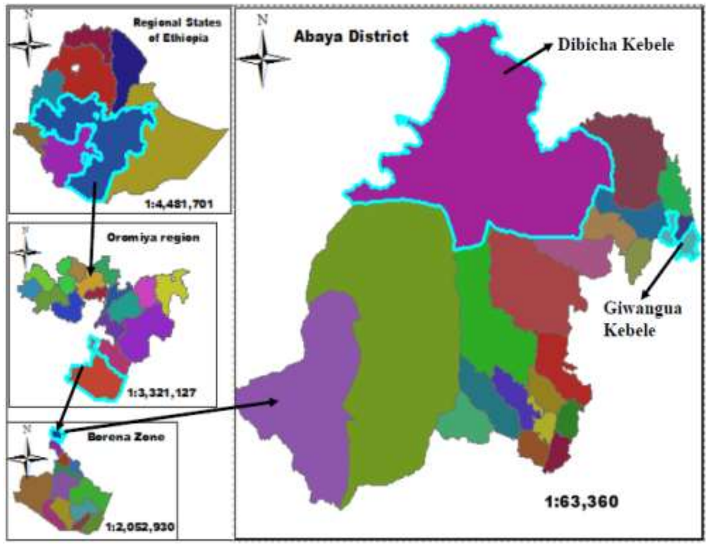
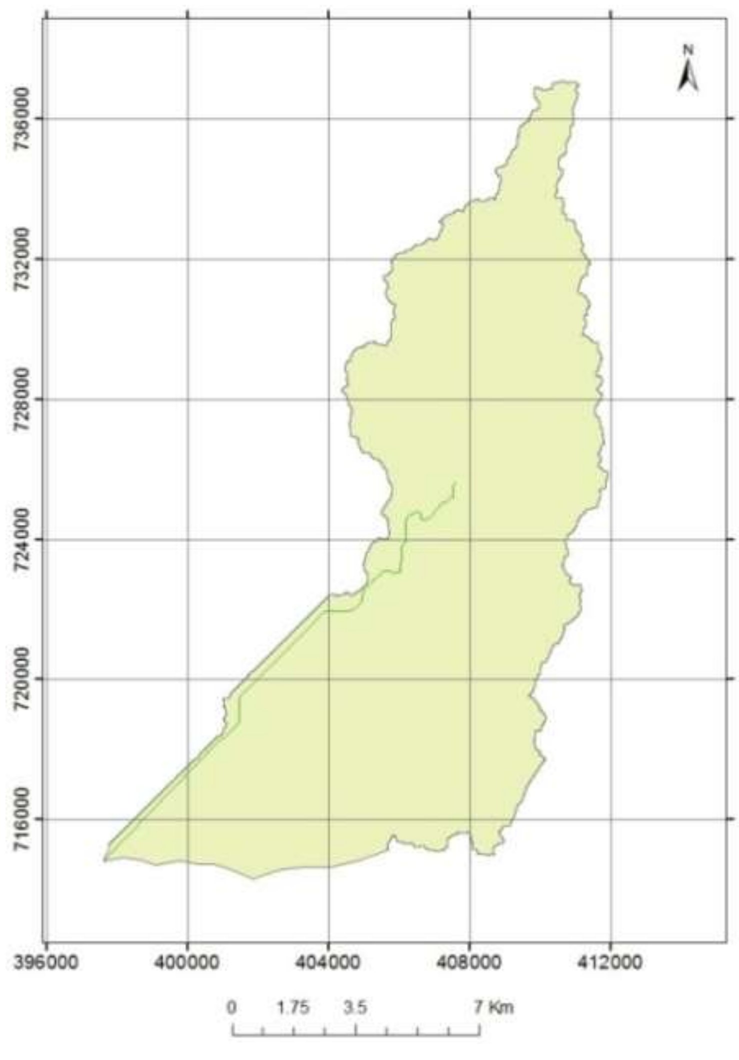


Figure 1. Location map of the study area.



Figures 2. Guangua badiya river basin.

Table 1. Soil suitability factor rating.

Factors	Factor rating			
	S1	S2	S3	N
Drainage class	Well	Imperfect	Poor	Very poor
Soil depth (cm)	>100	80-100	50-80	<50
Soil texture	L-SiCL, C	SL	-	-
Salinity	<8 mmhos/cm	8-16 mmhos/cm		
Alkalinity	<15 ESP	15-30 ESP		
Organic Carbon (OC)%	>10%	2-10%	-	<2%
Acidity and Alkalinity (pH)	5.5 - 7.0	5.5 - 4.5, 7.0 - 8.5	-	< 4.5, >8.5
Capacity(CEC) meq/100 g soil	35 - 70	35 - 16	-	< 16

Source: FAO guideline for land evaluation (1976, 1979 and 1991).

Table 2. Soil characteristics, limits and degree of suitability for surface irrigation.

Soil characteristics	Suitability			
	High (S1)	Moderate (S2)	Margional (S3)	Unsuitable (N)
ESP (%)	<10 (PH<8.5)	10-15 (PH>8.5)	15-30 (PH 8.5-9)	>30 (PH>9)
Topsoil Stoniness Vol. (%)	3-5 (fine gravel)	15-40	40-75	>75
Subsoil stoniness Vol. (%)	<10	15-40	40-75	>75

Source: Dent and Young (1981).

Ahmed et al., 2000). As such, this frame work utilized as a basis for this analysis, with further adaptation from method described in Dent and Young (1981). The land suitability evaluation was determined based upon topography and soil characteristics. Thus to determine land suitability for irrigation purpose, these soil characteristics were matched with the interpretation ratings for soil chemical characteristics (Tables 1 and 2) (FAO, 1976).

Data analysis

In watershed delineation, the Digital Elevation Model (DEM) with 30 m pixel was used. GIS uses DEMs data as input digital elevation model of the area was clipped from SRTM of NASA satellite with 30 meters resolution. DEM was provided good terrain representation from which watersheds could be derived automatically using GIS technology. The techniques for automated watershed delineation were implemented in various GIS systems and custom applications (Garbrecht and Martz, 1999). Land unit map was used as a guide in the field survey, soil sampling and, in turn, developing a more detailed soil analysis. The soil samples collected from the selected sites were air dried and ground to pass through a 2 mm size sieve in preparation for the analysis of all soil properties. Finally, the collected soil samples were analyzed for selected soil properties at the Hawassa Regional Soil Laboratory following the standard analytical procedures.

Soil analysis and data interpretation

The soil samples collected were air-dried, gently crushed using a mortar and pestle, and passed through a 2 mm-sieve to obtain fine earth separates. The processed soil samples were analyzed for some physical and chemical properties following the procedures outlined by FAO (1976) as briefly highlighted herein. Particle size analysis was determined by the Bouyocous hydrometer method as described by Gupta (2004). Stoniness was assessed by sieving. Soil pH H_2O suspension was determined with pH meter. The electrical conductivity (EC) of soils was measured from a soil water ratio of 1:2.5 socked for one hour by electrical conductivity method as described by Sahlemdhin and Taye (2000). The Walkley and Black (1934) wet digestion method was used to determine soil carbon content and percent soil OM was obtained by multiplying percent soil OC by a factor of 1.724 following the assumptions that OM is composed of 58% carbon. Exchangeable sodium percentage (ESP) was determined after analyzing sodium concentration and cations exchange capacity of the soil (% ESP = {Exch Na+}*100/CEC). Sodium concentration was determined using flame photometer; while CEC measurement was made by ammonium acetate method. The exchangeable sodium percentage was calculated, by dividing exchangeable sodium to cation exchange capacity.

Slope suitability analysis

Land slope is the most important topographical factor influencing land suitability for irrigation. To derive slope suitability map of the study area, digital elevation model of the area was clipped from SRTM of NASA satellite with 30 m resolution by masking layer of Guangua Badiya river basin. Then slope map of sub catchment was derived using the “Spatial Analysis Slope” tool in ArcGIS. The Slope derived from the DEM was classified based on the classification system of FAO (1996) using the “Reclassification” tool, which is an attribute generalization technique in ArcGIS. The four suitability ranges S1, S2, S3 and N were classified for surface irrigation as shown in Table 3.

Table 3. Slope suitability classification for surface irrigation.

Legend	Slope (%)	Factor rating
1	0-2	S1
2	2-5	S2
3	5-8	S3
4	>8	N

Table 4. Laboratory results of soil analysis for each mapping units.

Map unit	Soil depth (cm)	Depth (cm)	pH (H_2O)	ECe (ds/m)	Stoniness (%)	OC (%)	CEC (meq/100g	ESP (%)	Sand (%)	Clay (%)	Silt (%)	Texture
1	>100	0-40	5.97	0.61	2	6.8	20.4	0.34	38.56	42.88	18.56	Clay
		40-80	6.0	0.82	5	2.6	17.8	0.48	40.56	48.88	10.56	Clay
2	>100	0-40	5.56	0.27	1	9.5	19.5	0.64	32.56	46.88	20.56	Clay
		40-80	6.02	0.67	3	2.3	18	0.62	40.56	36.88	22.56	Clay loam
3	>100	0-40	5.71	1.02	1	8.3	25	0.51	38.56	40.88	20.56	Clay
		40-80	6.01	0.82	4	2.1	25.4	0.42	34.56	40.88	24.56	Clay
4	>100	0-40	6.23	1.05	2	4.9	25	1.88	14.56	56.88	28.56	Clay
		40-80	6.30	1.54	4	2.3	44	0.18	30.56	56.88	12.56	Clay
5	>100	0-40	6.22	1.14	2	2.8	26	0.27	30.56	34.88	34.56	Clay
		40-80	6.30	1.10	6	2.01	29	0.39	34.56	42.88	22.56	Clay

Source: Laboratory data (2014).

RESULT AND DISCUSSION

Physical land characteristics of the Guangua badiya sub basin for crops suitability

Soil depth, texture and stoniness

The soil depth of sub catchment as it was seen from auger-hole observation and profile description of soils, the soil depths at all sampling points were greater than 100 cm.

Thus the soil in the study area could be considered as deep soil. In all of mapping unit the surface and sub surface soil were dominated by clay. The maximum percentage of clay in the surface soil was observed as 100 percent on all mapping units, and the minimum percentage of clay was recorded as 80% in the sub-soil on mapping unit 2. No rock out crop was observed in the study area; however, there was a negligible coarse fragment.

As shown in Table 4, all mapping units showed that top soil stoniness and sub-soil stoniness were less than 3 and 10%, respectively. There was no significant variation of stoniness in volume percentage for all mapping units, but there was slight increase in volume percentage with regard to depth.

pH, salinity and sodicity

The soil pH (H_2O) values were found in the ranges of 5.6 to 6.3 (Table 4). Values of soil pH generally showed a slight increasing pattern with depth of the studied profiles. However, for both surface and subsoil horizons soil pH values were below 7 and can be rated to range from weakly acidic to slightly acidic in reaction. Thus the values which can be rated as weakly acidic according to the ratings given in Landon (1991).The highest pH value as 6.3 were observed on mapping unit-4 and 5 and the lowest as 5.6 was recorded on mapping unit-2. The salinity of soil measured as saturated extract ranged from 0.27 to 1.14 dS/m. The highest surface ECe reading was obtained on mapping units five. Due to the moderately acidic nature of the soils of the study area, the ECe values were negligible. Moreover, there was no significant difference in ECe values. This indicates that there would not be any actual and potential salinity hazard in the soils of the study area.

In terms of Na+ hazard or sodicity of the soil, ESP differed from a minimum of 0.18% and a maximum of 1.88% were observed in mapping unit-4. According to FAO (1979) soil classification as, majority of soil was found non-sodic, as carried on ESP value was less than 6%. Exchangeable Na were found in very low

Table 5. Land evaluation classes.

		Suitability class for land qualities				
Map units	**Soil depth (cm)**	**Effective soil depth**	**Texture**	**Stoniness**	**Salinity**	**Alkalinity (ESP)**
1	0-40	I	I	I	I	I
	40-80			I	I	I
2	0-40	I	I	I	I	I
	40-80			I	I	I
3	0-40	I	I	I	I	I
	40-80			I	I	I
4	0-40	I	I	I	I	I
	40-80			I	I	I
5	0-40	I	I	I	I	I
	40-80			I	I	I

Table 6. Slope suitability range of Gwangwa Badiya River basin for surface irrigation.

Slope range (%)	Area coverage (ha)	% of total area	Suitability classes
0-2	1303	9.31	S1
2-5	4558	32.56	S2
5-8	3335	23.82	S3
>8	4802	34.30	N
Total	13,998	100	

concentration in all mapping units and did not show significant variation as compared to the critical level that caused deterioration of soil structure and Na toxicity.

Evaluation of land suitability for irrigable site

Soil suitability

Summary of soil suitability classification results are given in Table 5. Results of soil analysis in the river basin indicated that major part of the area dominated by clay soil. The area characterized by deep soil, clay texture, well drainage condition, top soil stoniness, sub soil stoniness, soil salinity and soil alkalinity. So according to FAO (1976) guideline, in all parts of the areas, soil evaluation parameters are highly suitable for irrigation purpose.

Slope suitability

Slope has been considered as one of the evaluation parameters in land suitability for irrigation purpose, based on the four slope classes S1, S2, S3 and N. The result of land suitability of study area for the development of surface irrigation system (Table 6), indicated that 9.32% (1303 ha) are highly suitable, 32.5% (4558 ha) are moderately suitable, 23.82 %(3335 ha) marginally suitable and 34.30 (4802 ha) are not suitable for surface irrigation systems. Hence, the majority of the study area is highly to marginally suitable for surface irrigation in terms of slope suitability.

Overall evaluation

Sound information on soils, water and other land characteristics provide a basis for decision making on proper utilization and management of natural resources. The importance of land evaluation points to opportunities for influencing future developments of soils in the region using management techniques that are tailored to the characteristics of the landscape elements.

The final objective of the study was to evaluate land suitability for irrigation purpose. The overall result determined based on the analysis of soil characteristics and slope percentages. All land units, soil parameters result depicted that the study area has a deep soil, clay texture, well drainage condition, top soil stoniness, sub soil stoniness, soil salinity and soil alkalinity, which implies highly suitable (S1) for irrigation purpose.

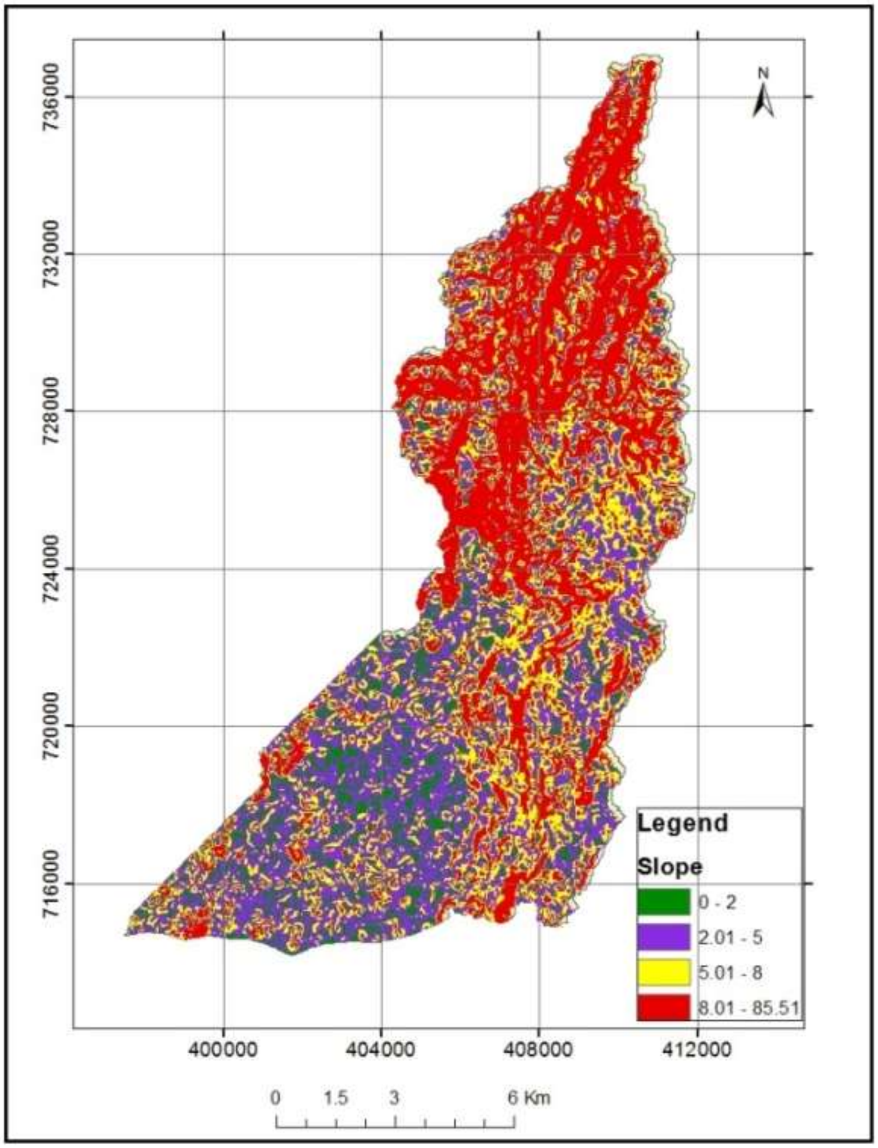


Figure 3. Slope classification of Gwangwabadiya riverbasin.

On slope percentages of land suitability show that, the DEM different types of colors were observed. The area with the same color means that those areas have the same surface elevation. The abrupt change of color indicates that there was a difference in elevation within short distance. From the DEM using GIS command (surface) the surface slope of the area was developed. This surface slope then grouped and a slope category was developed. The surface slope was categorized into four slope range, viz, zero to two percent (S1), 2 to 5% (S2), 5 to 8% (S3), and >25% (N) (Figure 3). These slope categories had an area of 1303, 4558, 3335 and 4802 ha, respectively. Based on FAO suitability classification for surface irrigation guideline (1976), 9.32% (1303 ha) are highly suitable, 32.5% (4558 ha) are moderately suitable, 23.82% (3335 ha) marginally suitable and 34.30 (4802 ha) are not suitable for surface irrigation systems. Hence, the majority of the study areas are in a range value of highly to marginally suitable for surface irrigation purpose. Due to high slope range currently 4802 hectares of lands are non-suitable for irrigation purpose.

Conclusion

The land evaluation of physical land qualities, chemical land qualities and slope of the study areas indicated that majority of Gwangwa badiya river basins (1303 ha) are suitable for surface irrigation. The factors which were considered for evaluation of the land for surface irrigation of the study area are: Slope of the land, soil depth, soil texture, soil type, soil chemical properties, and drainage nature. The most critical factor that determines gravity (surface) irrigation suitability is slope gradient.

Conflicts of Interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Effect of different container volumes and concentration of the controlled release fertilizer in the production of *Eugenia involucrata* DC. seedlings

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***Eugenia involucrata* DC. (Myrtaceae) stands out by its ecological potential, and it is indicated in planting in degraded areas and permanent preserved areas. Because of its importance, the work aimed to evaluate the effect of different container volumes and concentrations of controlled release fertilizer (CRF) in the seedlings emergence and the seedlings growth of *E. involucrata* in nursery. The experiment was conducted in Laboratory of Silviculture and Forest Nursery, Santa Maria, RS, Brazil. The fruits of *E. involucrata* were collected from eight trees in a fragment of Subtropical Seasonal Forest. For installation of the experiment, substrate which constituted of a mixture of 80% of commercial substrate mixed to 20% of carbonized rice husk was used. In this study, two container volumes (tubes with 110 and 180 cm^3 of capacity) and five doses of CRF (0, 3, 6, 9 and 12 g L^{-1}), were evaluated with four repetitions, using completely randomized design. The emergence variables, the emergence speed index and average time of emergence were analyzed, besides the height, stem diameter and relation height/diameter of the stem. The seedlings emergence had the beginning at 77 days after sowing, and it was established at 126 days. For production of seedlings indicated the use of container of 180 cm^3, allied to the dose of 12 g L^{-1} of CRF. Nevertheless, considering the long time necessary to the emergence and the slow species growth, the topdressing will be necessary since this fertilizer presents determined time of efficiency.**

Key words: Native species, fertilizing, forest nursery.

INTRODUCTION

Eugenia involucrata DC., belongs to the Myrtaceae family, occurs naturally in Argentina, Paraguay, Uruguay and Brazil (Carvalho, 2008). The species has antiulcer, anti-diarrheic and digestive medicinal potential (Sausen et al., 2009), antioxidant (Marin et al., 2008) and, according to Franzon and Raseira (2006), it has *in natura* or processed food utilization. Besides that, *E. involucrata* presents great ecological importance because it presents honey

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flowers and attractive fruit to the wild fauna, and it is indicated to the planting in areas of permanent preservation (Backes and Irgang, 2009).

In this way, considering the potentialities highlighted for *E. involucrata,* mainly in relation to its use in projects of riparian forest restoration, it becomes essential carrying out studies that focus on the quality of the seedlings, in special address of factors linked to its propagation, which according to Mendonça et al. (2009) and Alegretti et al. (2015) still lack information. In obtaining qualified seedlings, one should consider the different characteristics of growth of forest species, which can be partially controlled by silviculture, by means of adequate techniques of production, which consider the different types of containers and substrates, nutritional and hydric demands, among other aspects (Saidelles et al., 2009).

The choice of container to be used is very important for the seedlings production, implying additional costs with substrate when using containers that are bigger than the recommended ones (Viana et al., 2008). Besides, this influences the quantity of water and available nutrients for the seedling growth (Brachtvogel and Malavasi, 2010). The ideal size of the container depends on the characteristics of the species growth, on the substrate used and on the climate conditions, and it has influence on the development not only of the root but also the aerial part of the seedlings (Viana et al., 2008).

However, the use of containers with limited dimensions makes the root system subject to physical restrictions (Danner et al., 2007), mainly when associated with a long permanence of the seedlings in these containers, so it is necessary for specific studies on the distinct forest species as a way of subsidizing practical information to the nurserymen. In this sense, Souza et al. (2015) and Dutra et al. (2016) reported that the search for alternative components, ecologically viable and of low cost are of extreme importance for the seedlings propagation, as for example, the carbonized rice husk mixed to the substrate.

Besides the size of the container, the fertilization used is also considered a relevant factor for the good development of seedlings (Rossa et al., 2013). One of the fertilizers used for the seedlings production in nursery is denominated controlled release fertilizer (CRF), which, due to the slow and continuous release of nutrients, offers practicality to the seedlings production in containers, reducing the possibility of losses by leaching and maintaining the plant with available nutrients during determined period (Jacobs and Landis, 2009). Nevertheless, because of the elevated acquisition cost, it becomes fundamental to determine the adequate concentration for each species and systems of production (Rossa et al., 2013).

In this way, the aim of this work was to evaluate the effect of different volumes of container and concentrations of controlled release fertilizer in the seedlings production of *Eugenia involucrata* DC. in nursery.

MATERIALS AND METHODS

The experiment was conducted in Laboratory of Silviculture and Forest Nursery (latitude 29°43’14.3” South and longitude 53°43’17.5” West), at Universidade Federal de Santa Maria (UFSM), Santa Maria, RS, Brazil. According to the classification of Köppen, the Santa Maria climate is subtropical, with rains during all year, presenting annual average precipitation of 1700 mm, average temperature of the hottest month superior to 22°C, and of the coldest month superior to 3°C (Alvares et al., 2013).

The fruits of *E. involucrata* were collected from eight trees in a fragment of Subtropical Seasonal Forest (latitude 29°39’13.3” South and longitude 53°28’43.7” West), in the municipality of São João do Polêsine, RS, Brazil. The extraction of seeds was carried out manually by removing the pulp from the fruits, in running water, with the help of a sieve and after this process, it was performed the natural drying of the seeds under the shadow, under environmental temperature and humidity (Carvalho, 2008). After the processing, the seeds remained stored in cold chamber, with temperature of ± 8°C and relative humidity around 80%, in paper bags inside barrels of Kraft paper, during 14 days (Figure 1).

For installation of the experiment, conical tubes of polypropylene, with capacity of 110 cm^3 (6 stripes, internal diameter of 35 mm and height of 13.5 cm) and 180 cm^3 (8 stripes, internal diameter of 52 mm and height of 13 cm), accommodated on plastic trays suspended to 16 cm over the ground surface was used. The substrate used was constituted of a mixture of 80% of commercial substrate (composed of *Sphagnum* peat, expanded vermiculite, dolomitic limestone, agricultural plaster and NPK fertilizer) mixed to 20% of carbonized rice husk (CRH) (Figure 1). The physical and chemical analysis of the substrate (Table 1) was performed by Laboratory of Analysis of Substrates for Plants (Laboratório de Análises de Substratos para Plantas - LASPP), State Foundation of Agriculture and Cattle Raising Research (Fundação Estadual de Pesquisas Agropecuárias).

The sowing was carried out directly in the tubes putting three seeds by container. Approximately 150 days after sowing (DAS), it was performed the thinning, eliminating the exceeding seedlings, leaving only one by container, the most central and vigorous. The experimental design used was entirely randomized, in factorial scheme 2 × 5, and the factor A was represented by two volumes of container (tubes of 110 and 180 cm^3), the factor B by five concentrations of controlled release fertilizer miniprill (NPK 18:05:09) (0, 3, 6, 9 and 12 g L^{-1}), with four repetitions per treatment. The useful parcel for assessment of seedlings emergence was composed by 24 seedlings, and at the 150 DAS it was the alternation of the same was performed, remaining 13 interleaved seedlings. The assessment of emergence was performed every seven days, from the date of experiment installation, by means of visual observation and registration of the emerged seedlings. From these results, it was possible to determine the Emergence (E), Emergence Speed Index (ESI) and Average Time of Emergence (ATE). After the period of emergence, at the 180 DAS, it was the beginning of the assessment of the growth by means of height (H) and stem diameter (SD) measurement, every 30 days, with the help of a millimeter ruler and digital calliper (precision of 0,001 mm), respectively, which allowed the obtaining of the relation height/stem diameter (H/SD).

In the data analysis, the test of Shapiro-Wilk was used to verify the normality of residues and of Barlett to homogeneity among the variances. Besides that, the data was submitted to variance analysis, aiming to verify the existence of interaction, and subsequently submitted to the regression analysis. In the case of significant effect of quadratic equations, the dose of maximum

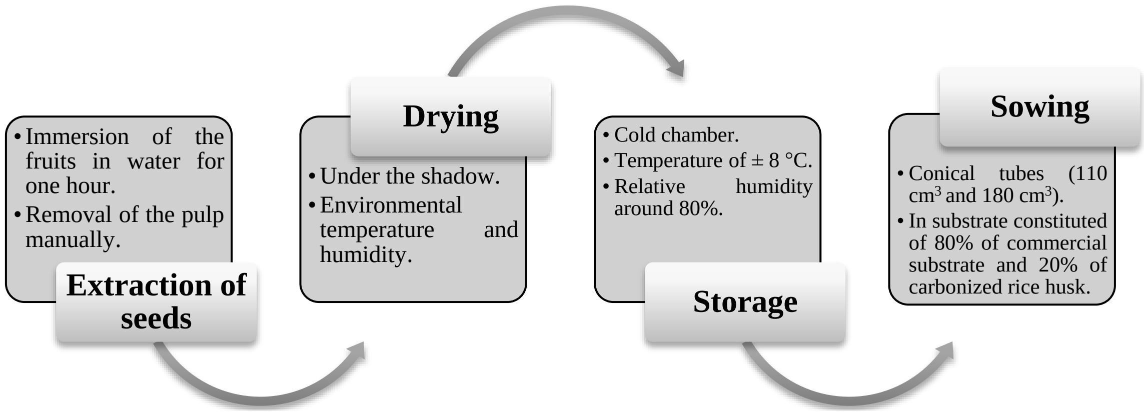


Figure 1. Diagram of the steps involved in the processing, storage and sowing of *Eugenia involucrata* seeds.

Table 1. Physical and chemical properties of the substrate used for the production of *Eugenia involucrata* seedlings.

Parameter	HD (kg m^{-3})	SA (%)[1]	WEA (%)[1]	EC (dS m^{-1})	Classification (EC)[2]	pH	Classification (pH)[2]
Substrate	278	30.6	23.7	0.41	Normal	6.1	Adequate

In which: Substrate: 80% commercial substrate and 20% carbonized rice husk; HD: Humid Density; SA: Space of aeration; AFD: Water Easily Available; EC: Electrical Conductivity. [1]Schmitz; Souza; Kämpf (2002) quoted SA ideal = 30% and WEA = 24 at 40%; [2] Regan (2014).

technical efficiency (DMTE) was determined. For the analysis, the statistical software SISVAR was used (Ferreira, 2014).

RESULTS AND DISCUSSIONS

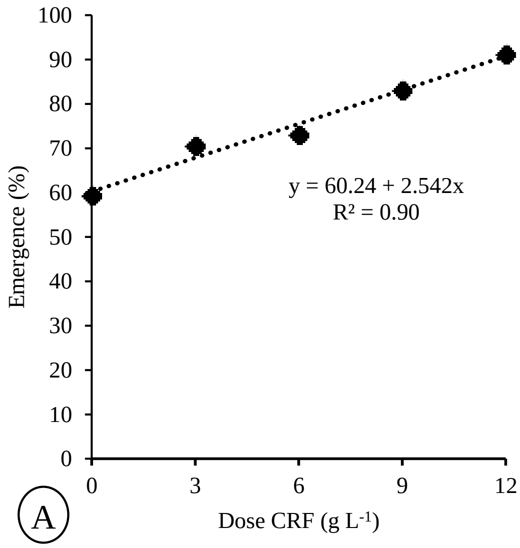
The emergence of *E. involucrata* seedlings had the beginning at the 77 days after sowing, establishing itself at the 126th day. Carvalho (2008) related that the emergence of seedlings of this species can be observed initially at the 30 to 40 days after sowing, generally, it is associated to the low germinal performance, diverging from the results obtained in this work, which presented slow emergence, but with elevated values. Prado (2009) studying the self-ecological and silvicultural aspects of this same species verified that despite a small number of seeds answered fast, emerging at the 25 days after installation of the experiment, the majority presented emergence until the second month after sowing, and the emergence could be observed until the 150 days, confirming the slow species emergence.

Analyzing the emergence (E), emergence speed index (ESI) and average time of emergence (ATE) in *E. involucrata* seedlings submitted to different concentrations of CRF, we determined significant difference for emergence (E%) and emergence speed index (ESI). The species presented greater averages not only in E (%) (91.2%) (Figure 2A), but also in ESI (0.19) (Figure 2B), when produced with 12 g L^{-1} de CRF (Figure 2).

In this way, the greatest dose of fertilizer used did not compromise the initial phase of the seedlings emergence, and it does not provide an elevated salinity in the initial phase of development. Besides that, associating to the recalcitrant characteristic of seeds from this species (Wielewicki et al., 2006), as well as the slow emergence and growth, can infer that the availability of seedlings for commercialization and/or using in programs of areas recovery depends on the immediate sowing after collection, maintaining a seedling bank in the nursery, to be handled for seedlings expedition in field.

According to the variance analysis, the triple interaction (volumes of container × doses of CRF × time) was not significant for any of the analyzed morphological variables (H, SD and H/SD). There was significant interaction between the container × doses of CRF for H, SD and relation H/SD of seedlings (Figure 3).

Seedlings of *E. involucrata* presented greater averages both in H and SD, when produced in tubes of 180 cm³, with 12 and 9 g L^{-1} of CRF, respectively. Gasparin et al. (2015) highlighted in *Parapiptadenia rigida* (Benth.) Brenan that the tube of 180 cm^3 combined with the dose of 9 g L^{-1} of CRF, obtained the best results for the analyzed morphological variables (H, SD and H/SD), allowing seedlings of quality for planting in field. In a similar way, Stüpp et al. (2015) evaluating different sizes of tubes and doses of CRF for the seedlings production



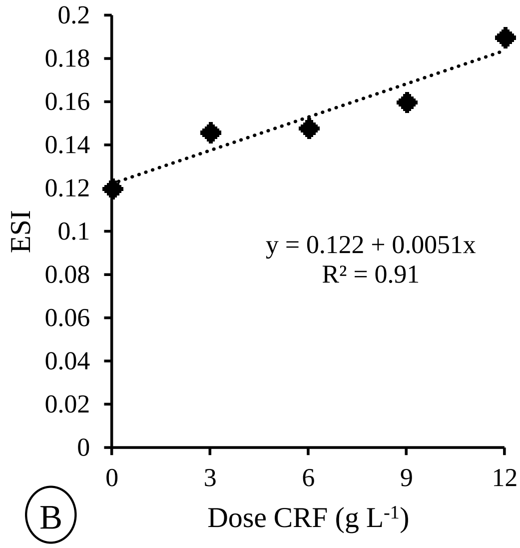


Figure 2. Percentage of Emergence (A) and emergence speed index (ESI) (B) of *Eugenia involucrata* seedlings in controlled release fertilizer doses (CRF).

of *Mimosa scabrella* Benth. concluded that the doses of fertilizer influenced on the initial growth of seedlings, and the greatest growth was obtained with the use of tubes of 180 cm³ and 6 g L^{-1} of CRF. In both studies, the best results both in H and in SD were obtained with the use of bigger containers, in the case the tube with 180 cm^3, which can be attributed to the greatest volume of available substrate and the smallest restriction for the root growth of seedlings.

Berghetti et al. (2016) highlighting that *Cordia trichotoma* is responsive to fertilization, and that bigger increments can be obtained under the greatest volume of substrate and doses of CRF, when we maintain the waiting nursery. Besides that, the positive result of the use of CRF can be explained by the fact that this fertilizer releases the nutrients gradually as the resin that involves the granules of the same is dissolved, maintaining the availability of the essential elements during the period of seedlings growth (José et al., 2009). Mendonça et al. (2008) affirmed that the use of CRF provides, through a single application, the continuous supply of nutrients throughout the development of the plant, reducing the occurrence of nutritional disability symptoms, dispensing the parceled applications of other sources (topdressing), since that it is considered the release period of the fertilizer, which is informed by the manufacturer.

The greatest growth in H and SD in *E. involucrata* seedlings when produced in tubes of 180 cm^3 of capacity, with 12 and 9 g L^{-1} of CRF, respectively, deserves highlight. The answer provided by both morphological variables is considered as one of the main parameters for selection of seedlings for planting (Ritchie et al., 2010), because they provide an estimate of initial potential growth and survival of seedlings in field (Wendling and Dutra, 2010). According to these authors, seedlings that are able to be planted should present SD of 2 mm, and values superior to the related by these authors are found, in the conditions described.

The maximum dose of technical efficiency (MDTE) estimated for height was of 9.14 g L^{-1} for the tube of 110 cm³ and 13.9 g L^{-1} for the tube of 180 cm³ (Figure 3A). For stem diameter, the MDTE was of 25.9 g L^{-1} for the tube 110 cm³ and 8.8 g L^{-1} for the tube 180 cm³ (Figure 3B). For the variables height and stem diameter the interaction between the doses of CRF and the time of assessment (Figure 4) was also verified. At the end of the 180 days the greatest averages in height in the seedlings submitted to the greatest dose of CRF (Figure 4A) was found, since for the stem diameter the greatest averages used were 9 g L^{-1} (Figure 4B).

Because it presents slow growth, this species needs some greater time of permanence in nursery, which elevates the cost of seedlings production, because it increases the necessity of labour as well as the successive applications of fertilizers and defensives. Additionally, with the use of containers as tubes, although the quantity of substrate used is lower, the frequent irrigation tends to provide the leaching of nutrients (Guareschi et al., 2015), highlighting thus the necessity of performing adequate fertilizations for the good development of the seedlings in nursery. In this sense, it is recommend that in the seedlings production of *E. involucrata*, concomitant to the use of 12 g L^{-1} of CRF, the topdressing is performed, which will be necessary, considering the low species growth and the determined time of the efficiency of the fertilizer.

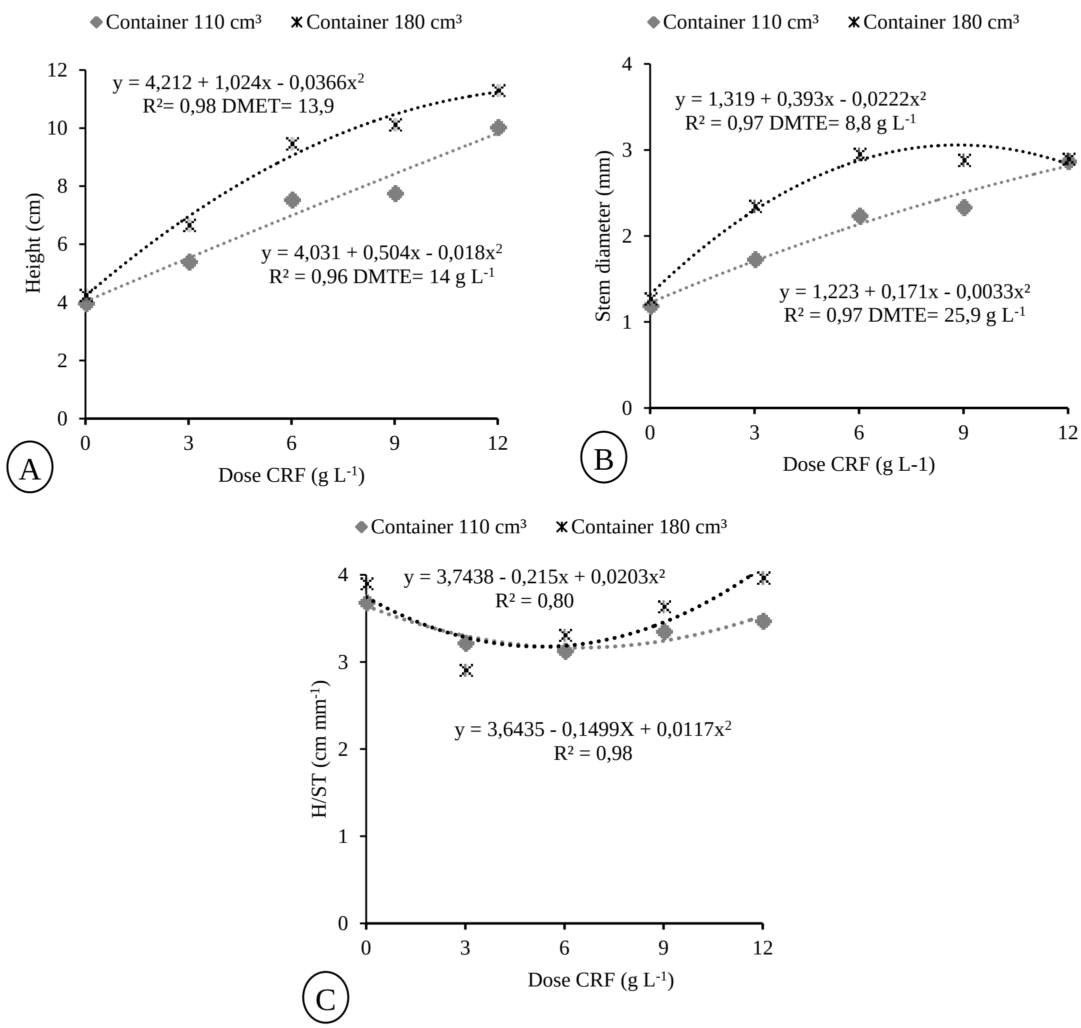


Figure 3. Effect of the container volumes and concentration of the controlled release fertilizer on Height (A) and stem diameter (B) and H/SD (C) of *Eugenia involucrata* seedlings.

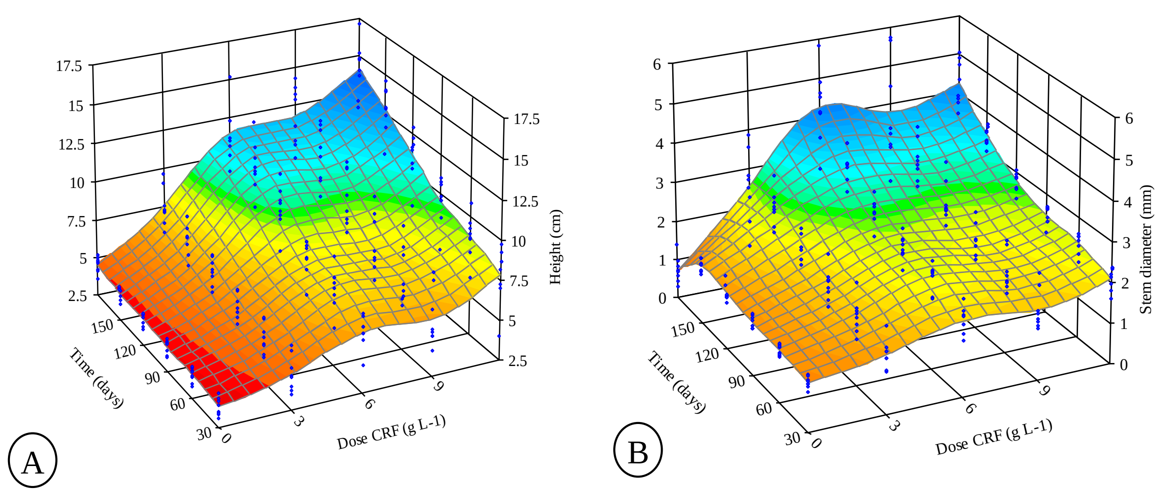


Figure 4. Contour graphs representing the effect of the time and the concentration of the controlled release fertilizer on height (A) and stem diameter (B) of *Eugenia involucrata* seedlings.

Conclusion

The emergence of *Eugenia involucrata* had the beginning at the 77 days after sowing, and it was finished at the 126 days. For the production of seedlings in nursery, the container of 180 cm^3, allied to the dose of 12 g L^{-1} of controlled release fertilizer is necessary. However, considering the long time necessary to the emergence and the slow species growth, the topdressing will be necessary since this fertilizer presents determined time of efficiency.

Conflict of interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Electric energy consumption and economic feasibility of led lighting system in broiler house

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This study aimed to compare the performance of incandescent lamps and LED lamps, regarding the consumption of electricity and the economic viability of these lighting systems in broiler houses in western Paraná State, Brazil. The study was conducted to compare the power consumption in two broiler houses of the dark house type in São Miguel do Iguaçu, Paraná, Brazil; one lighting system with incandescent lamps and the other one with LED lamps. The power consumption was measured in the two lighting systems, using meters of electrical quantities Landis Gyr+ during the housing period of a batch of poultry corresponding to 43 days. Then, the energy consumption was calculated per bird housed, by mass of live chicken and aviary unit area. With the electricity tariff values for rural consumers, there was an evaluation of the economic viability of lighting systems by the method of net present value (NPV) method and the discounted payback. The main results showed that throughout the period of broiler chickens housing, in the aviary with incandescent lamps 1,768 kWh in lighting was consumed, while the aviary with LED lamps consumed 221 kWh. The economic feasibility analysis showed that the use of LED lamps presented greater economy, and has a return on investment within a period of 21 months.

Key words: Energy consumption, lighting systems, broiler house.

INTRODUCTION

The Brazilian poultry industry is responsible for thousands of integrated producers, processing companies and exporters. The poultry sector employs over 3.6 million people directly and indirectly, and accounts for almost 1.5% of the national gross domestic product (GDP) (UBABEF, 2014).

The national poultry industry uses imported tech-nologies temperate climates, using adaptations without considering the growing concern for the rational use of energy in relation to the environment (Bonn, 2010). As this activity is dependent on electricity, mainly due to commercial-scale productivity, energy consumption in the production

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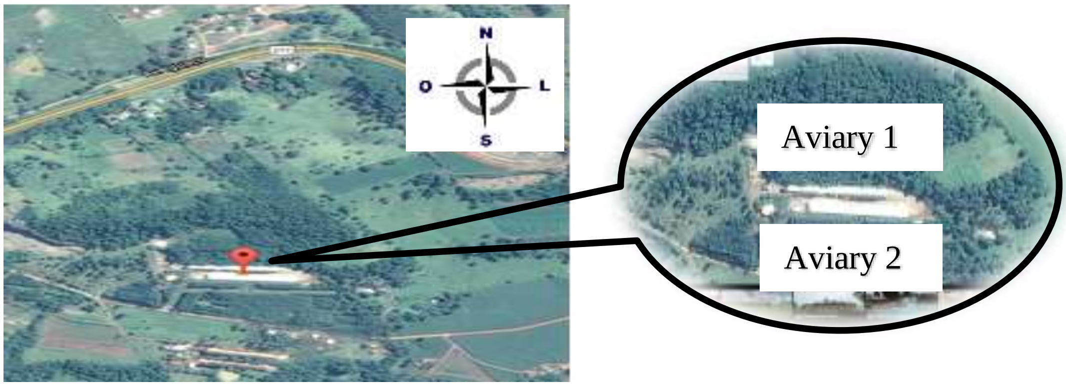

Figure 1. Location of aviaries 1 and 2 of the study (Google maps, 2015).

becomes limiting, making the poultry sector seek increased energy efficiency. According to Saidur (2009), this reduction in power consumption, can constitute a simple replacement of inefficient light bulbs with more efficient light bulbs.

According to Simpson et al. (2014), regarding the poultry industry, the light is an important aspect and is presenting developments in lighting systems in aviaries during the past years. Until 2007, the production of broiler chickens depended almost entirely on incandescent lamps. From 2008, producers began to replace incandescent lamps with spiral compact fluorescent lamps not dimmable, for laying chickens, and for termination, used to dimmable CFLs. This process resulted in an annual electricity bill reduction of US$ 1,000 for aviaries of 1,800 m².

Santos et al. (2015) and Simpson (2008), report that incandescent lamps produce light by heating the tungsten filament. For this reason, the luminous efficiency is in the range 10-20 lm/W. Depending on its construction and the filament operating temperature, the rated life of these lamps is approximately 1,000 h. According to Brunner et al. (2010), incandescent lamps are considered inefficient light sources, because 95% of the consumed electrical energy is dissipated as heat. According to Reynolds et al. (2012), despite the fact that cost of the incandescent lamp is much less, in the long run, the cost may be increased due to the high consumption of electricity. As stated by MME (2011), according to the Ministry of Mines and Energy of Brazil, the incandescent lamp is inefficient and through an interministerial decree No. 1,007 of December 31, 2010, which sets minimum levels of energy efficiency for incandescent lamps, prohibits marketing and imports from June 30, 2016.

FUPAI (2006) reported that LED lamps are composed of semiconductors that convert electrical current into visible light in a solid state. The main advantage is its small size and technological development, making it an interesting alternative to the replacement of incandescent lamps. According to Osram (2014), the LED lamp has energy efficiency of about 100 lm/W in the white light illumination. Simpson et al. (2014) comments that, from 2008, new light-emitting diodes (LED), became available.

Abreu and Abreu (2011) reported that the aviaries type dark house, can possess light protection and natural ventilation, held by Curtain sider sealing black polyethylene on one side and reflective on the other or use steel plates insulated with rigid foam polystyrene (XPS) for sealing. The aviary type dark house provides greater control of lighting and thermal conditions inside the aviary. As stated by Nowicki and Butzge (2011), in this type of aviary, the birds are subjected to totally artificial light and controlled light program, ventilation and relative humidity as well. This combination of controlled ventilation and light makes the broiler become quieter and consume less energy for their development.

In order to show the possibility of power consumption reduction in aviaries and demonstrate the economic viability, this article compared the performance of conventional incandescent lamps with the performance of LED lamps based on their energy consumption in their final use in two broiler houses type dark house in São Miguel do Iguaçu city, western Paraná, Brazil (Figure 1).

MATERIALS AND METHODS

The aviary 1 was built about 8 years ago, works in the system dark house and has the capacity to house 23,000 broilers. Its dimension is 12 x 150 m (total area of 1,800m2) and ceiling height of 2.60 m. The sides are insulated with polyethylene sheeting and coverage with fiber cement tiles with 6 mm.

The aviary 1 lighting system is composed of 3 rows of 22 incandescent 60 W lamps of 127 V, a total of 66 lamps installed. The control of the illumination system is done by means of a panel with a Fan control dimmer equipment (Figure 2).

The aviary 2 which was built about 2 years ago works in the system dark house and has the capacity to house29,000 broilers. Its dimension is 14 x 150 m (total area of 2,100 m2) and ceiling height of 2.45 m. All lateral walls were sealed through a system of double aluminum plates, expandable polystyrene (EPS) coated, filling the heart of this system is through the use of extruded polystyrene (XPS). The doors also have insulation with aluminum. The external side of the aviary is painted in white.

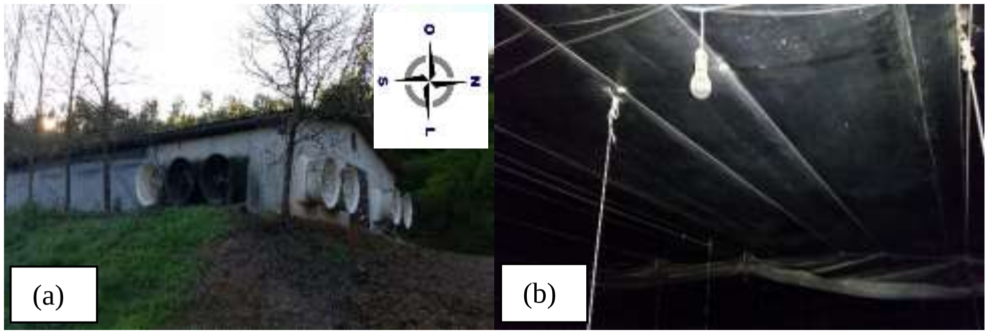

Figure 2. (a) Aviary 1, dark house system without thermal insulation. (b) Lighting with incandescent lamps in aviary 1.

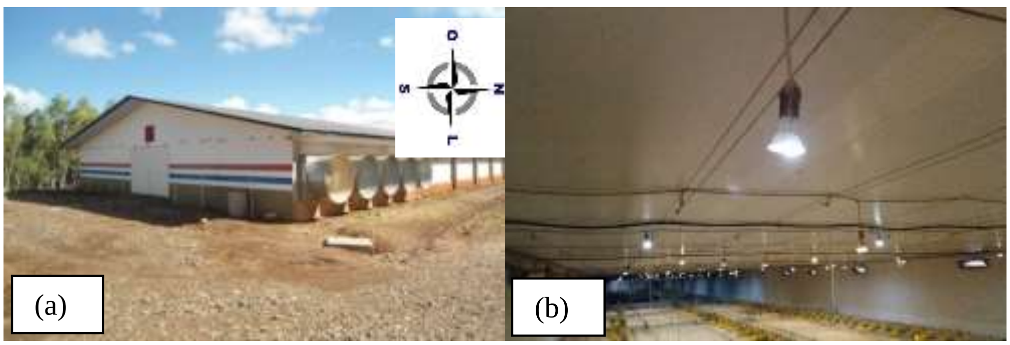

Figure 3. (a) Aviary 2 with thermal insulation and lining with thermal blanket. (b) Lighting with LED lamps in aviary 2.

Figure 4. Measuring instruments installed in the scenarios 1 and 2.

The aviary 2 lighting system consists of 3 lines of thirty-three 5W LED lamps, for a total of 99 lamps installed. The control of the illumination system is done by means of an Avilamp panel, which has a converter 220V/24 V to power the system (Figure 3). The authors used the brand meters Landis Gyr+ ZD318 model, that store the active power consumption for net connection in 3-phases, 4-wires; 2-phase, 3-wire; connected in 120 or 240 V, 50 or 60 Hz and currents up to 120 A. It has standard optical interface ABNT (brazilian standard); diode (LED) test and its reading is recorded every 1 Wh/pulse (Figure 4).

Initially, there was the technical inventory of the two aviaries lighting system. Also, broiler chicken production information, housing area, density of broiler/m² and total output weight of the broiler in each aviary were collected (Table 1).

To perform the measurement of electricity consumption, the brand meters Landis Gyr+ Z.D.318 model was used. In aviary 1, an equipment Landis Gyr+ was installed in order to collect data from electric power consumption of 66 power incandescent lamps of 60 W. In aviary 2, other equipment Landis Gyr+ was settled to measure the electric power consumption of 99 LED lamps of 5 W.

The data generated by the meters were collected daily. The beginning of the data collection took place on June 18, 2015 (date

Table 1. Technical characteristics of the aviaries.

Description	Aviary 1	Aviary 2
Aviary area (m²)	1,800	2,100
Input housed broiler (un.)	23,000	29,000
Slaughter output broiler (un.)	21,698	27,334
Density of broiler (broiler/m²)	12.78	13.81
Output total live broiler weight (kg)	60.732,70	72.571,77

Table 2. Electric energy consumption of lighting systems on each aviary.

Description	Aviary 1	Aviary 2
Total eletric energy consumed (kWh)	1,768.00	221.00
Eletric energy consumed (kWh /housed broiler)	0.0815	0.0081
Eletric energy consumed in lighting (kWh/m²)	0.9822	0.1052
Eletric energy consumed (kWh /kg of live broiler)	0.0291	0.0030

of housing broiler) and ended on July 31, 2015 (date of transport of broiler for slaughter). The electrical quantity measured was the active energy (kWh), collection of data of total consumption, consumption during normal business hours (6:30 to 21:30) and consumption on schedule (NRR) with nocturne rural rate (21:30 to 6:30). The property works with conventional charging rural B2 group with nocturne reduced rate.

To calculate the electric energy consumption in kWh/housed broiler, the energy consumption in kWh/m² and electricity consumption in kWh/kg of live broiler, the following equations were used:

$$EECHB=TEEC/(\text{housed broiler amount}) \quad (1)$$

$$EECAU=TEEC/(\text{aviary area}) \quad (2)$$

$$EECBLM=TEEC/(\text{total weight of live broiler}) \quad (3)$$

Where, EECHB = Electric energy consumption by housed broiler, kWh/housed broiler; EECAU = Eletric energy consumption by area unit, kWh/m²; EECBLM = Electric energy consumption by live broiler weight, kWh/kg of broiler live; TEEC = Total electric energy consumption, kWh.

To perform the economic feasibility analysis of incandescent lamps as compared to LED lamps, the calculation of net present value (NPV) and discounted payback were used considering interest of 5% per year, taking into consideration the following information:

Aviary 1: Lifetime of incandescent lamps (1,000 h), the cost per kWh, the initial cost of buying the bulbs and the cost of exchanging all the bulbs when they reach the rate life (every 60 days).

Aviary 2: Lifetime of LED lamps (50,000 h), the cost per kWh, the initial cost of buying the bulbs and control panel and the cost of exchanging all the bulbs when they reach the rate life (6th year).

RESULTS AND DISCUSSION

In this study, two aviaries type dark house with different building systems were evaluated, in São Miguel do Iguaçu city, Paraná, Brazil. With the data collected by the equipment Landis Gyr+, it was possible to know the total consumption of electricity in the two aviaries (Table 2). The variation in the consumption between the aviaries was considerably high. The aviary 2 showed consumption difference of 8 times lower for aviary 1.

The lighting program was the same for both aviaries using 4 to 12 days 100% of illumination, 13 to 20 days 80%, 21 to 30 days 60% and 31 days before slaughter 45% lighting. Comparing the consumption of aviary 1, which was 0.0291 kWh/kg of broiler live (incandescent lamps) with the aviary 2, the power consumption was 0.0030 kWh/kg live chicken (LED lamps); it may show that the electricity consumption of aviary 2 was more cost-effective (Table 2).

This is confirmed in the study of Rajaniemi and Ahokas (2015) with the electricity consumption in lighting by using 84 fluorescent tube lamps of 36W, in an aviary of 1,600 m² in size and capacity of 28.000 housed broiler. Rajaniemi and Ahokas (2015) obtained on average 606 kWh per lot or 0.013 kWh/kg of broiler live which makes the aviary 2 with LED lamps even more energetically attractive.

As shown in Figure 5, the highest consumption for the two aviaries was in the beginning of the accommodation, as from the second week, the lighting program begins. According to López et al. (2007), Nascimento (2011) and Abreu and Abreu (2011) when the light program is correctly applied, it is one of the factors that contribute to the efficiency of the production lot.

In the first week, there was a sudden drop in temperature reaching 7°C. As stated by Brunner et al. (2010) and Pan (2015), incandescent lamps turn up to95% of the energy used into heat, which is energetically inefficient. As the aviary 1 is laterally closed with polyethylene tarpaulins and this has many air intakes, it hindered the room heating; however, benefited from this inefficiency of incandescent lamps to assist in adjusting

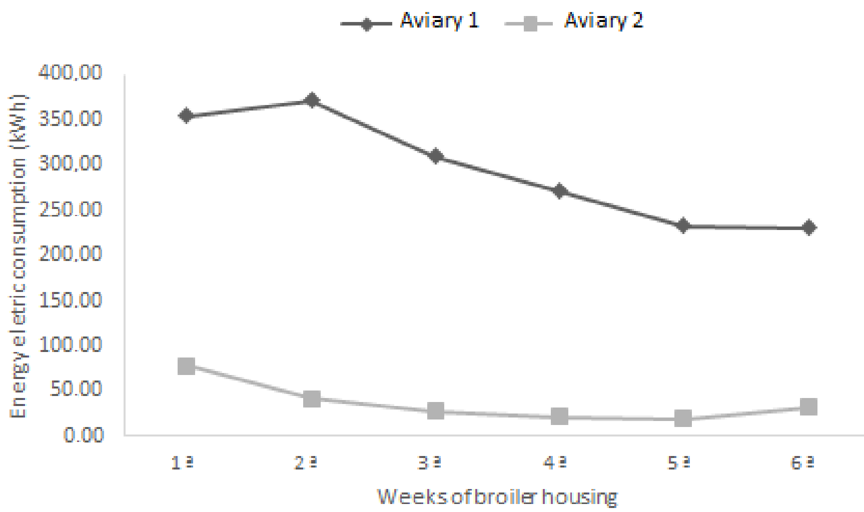

Figure 5. Eletric energy consumption (kWh) of the lighting system in the aviaries 1 and 2, during the six weeks of broiler housing.

Table 3. Electric energy consumption of the aviaries (kWh) working in the nocturne light program.

Nocturne light program	%	Work hours	Aviary 1		Aviary 2	
			Daytime (kWh)	Nocturne (kWh) **	Daytime (kWh)	Nocturne (kWh)**
1 and 12	100%	288	287	206	36	26
13 and 20	80%	134,4	263	66	33	8
21 and 30	60%	129,6	247	164	31	21
31 and 43	45%	324	241	294	30	36
Maintenance*	100%	84	144	0	18	0
Total		960	1182	730	148	91

*Empty aviary for maintenance, 7 days a week with 12 h worked during regular hours. **NRR– nocturne reduced rate.

Table 4. Energy electric cost in the aviaries 1 and 2.

Description	Aviary 1		Aviary 2	
	Consumption (kWh)	R$	Consumption (kWh)	R$
Daytime rate consumption	1,182	R$404.31	148	R$54.08
Nocturne rate consumption	730	R$101.31	91	R$14.06
Energy eletric cost in 60 days		R$505.62		R$68.14

the internal temperature. This generated a peak in electricity consumption as shown in Figure 5.

To perform the economic feasibility analysis of incandescent lamps in relation to the LED lamps, the values collected were used, days of the light program and its percentage and days in the aviaries were empty for cleaning as shown in Table 3. To calculate the NPV, it was considered the replacement of incandescent lamps every 60 days and LED lamps every 6 years.

In Table 4, it is shown, the total electric energy consumption and the cost of aviaries 1 and 2, considering the values provided by the dealership tariff in regular time, R$0.342030 and nocturne rural rate (NRR), R$0.138808.

The information and annual total cost of the implementation of each light bulb model are shown in Table 5.

Table 5. Total investment cost in relation to rate life.

Description	Incandescent*	LED**
Rate life of lamps (hours)	1,000	50,000
Quantity (un.)	66	99
Cost per unit	R$2.00	R$39.60
Panel cost	R$0.00	R$1,644.60

*Incandescent lamp: 60 days until replacing; **LED lamp: 6 years until replacing.

The calculation of net present value (NPV) and discounted payback period were used, considering an interest rate of 5% per year. The NPV lighting system with incandescent lamps was R$19,260.09 and NPV lighting system with LED lamps was R$7,620.76. Therefore, by the NPV, it is concluded that the system with LED lamps showed a lower investment cost. The investment analysis of the discounted payback indicates that the LED lamps system achieves a return on investment in 21 months.

Conclusion

The results of this study showed that in the period of June 18, 2015 to July 31, 2015, the aviary 1 consumed in lighting system, equivalent of 1,768 kWh and aviary 2, consumed 221 kWh. In financial terms, this LED lamps system obtained a saving of R$437.48 and analysis shows that an average of 6 lots per year can be achieved with savings of R$2,624.00 yearly.

Through the NPV calculation, the aviary 2 showed lower cost considering 72 months of investment and with the calculation of the discounted payback, this initial investment has its return in 21 months.

It is concluded that with the electricity consumption and also the economic viability calculation (NPV and discounted payback), the LED lighting system is an efficient energy and economically viable as compared to incandescent lighting system in this case.

Conflict of interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Effects of different tillage systems and plant densities in corn silage yield

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In order to investigate tillage systems and plant densities effects on corn (*Zea mays L.cv.sc704*) silage yield and component after harvesting wheat, an experiment was carried out in randomized complete block design in a strip plot. Treatments were arranged with four replications in Agricultural and Natural Resources Research Center Station of Dashte-Naz in Mazandran, Iran, for two years in 2012 and 2013. Tillage systems had three levels: 1. Plow and Disk system (PDS). 2. Disk system (DS). 3. No tillage (NT). Other factor was plant density in four levels (70000, 80000, 90000 and 100000 plant/ha). The results indicated that most silage yield (55.62 ton ha^{-1}) was obtained from Plow and Disk system (PDS) in density of 70000 plants/ha, that had no significant difference effects in comparison with No tillage system (NT) in density of 90000 plants ha^{-1} with silage yield of 53.39 ton ha^{-1}. The results also indicated that most dry forage yield (18.09 tons ha^{-1}) was obtained from Disk system (PDS) in density of 70000 plants ha^{-1} that had no significant difference effects in comparison to No tillage system (NT) in density of 90000 plants ha^{-1} with silage yield of 17.99 ton ha^{-1}. According to results, best treatment was No tillage system (NT) in density of 90000 plants ha^{-1}.

Key words: Corn, plant density, silage yeild, tillage system.

INTRODUCTION

Conservation tillage systems can be an important part of a sustainable agricultural system, in that they can be used to decrease soil erosion losses ordinarily associated with typical conventional agricultural practices. It is important to remember that anything that is done to decrease erosion losses also decreases need to add as much fertilizer and water soils, given that top soil generally contains most organic matter. Conservation tillage also, ideally, decreases water pollution (via decreasing soil erosion), saves fossil fuel energy and thus decreases CO_2 emissions, compared to conventional tillage systems. Because soil organic matter tends to increase under conservation tillage, as compared to conventional plowing, soils are also more effective to carbon storing.

Conservation tillage systems include a variety of techniques, including "no-till" "minimum till" "ridge till" "chisel plow" and "mulch till". The Soil Conservation Service (now called the Natural Resources Service) refers to these systems as "residue management". Conservation tillage is basically, any system of cultivation that reduces soil or water loss when compared to conventional moldboard plowing, which turns over the soil completely. Most definitions specify that at least 30% of the crop residue must remain on the soil surface at the time of planting. It was designed to conserve soil, water, energy,

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and protect water quality (Mitchel et al., 2015). Soil compaction can cause unfavorable soil physical, chemical and microorganism conditions in subsoil, which hinder root growth and crop yield (Mosaddeghi et al., 2009).

According to survey results from Conservation Technology Information Center (CTIC) (Sare, 2014), most operations in Midwest that use a cover cropping system do so in tandem with no-till practices or organic production, to help mitigate potential negative effects with these particular systems in comparison with traditional tillage or non-organic methods, respectively. Soil tillage also modifies mineralization rates of nutrients, which feeds back on soil carbon input (Barré et al., 2010). No-till is a growing practice for soil conservation (Horowitz et al., 2010).

Soil compaction had negative effect on soybean production (Acuña and Villamil, 2014). Penetration of plant roots through compacted soils is difficult (Chen and Weil, 2010). Corn (*Zea mays* L.) silage production is very important in winter in north of Iran that producer need to forage, but deceasing temperature and solar energy in delay sowing date resulting in low silage yield because farmers used from common plant density, row spacing and plant pattern.

Corn (*Z. mays* L.) is the most important grain-forage crop in Iran. The average grain yield of corn is more than 8 t/ha and it increase annually. In order to optimize moisture use, nutrients and solar radiation and corn seeds must be plant under optimum density and tillage system. Intensive production of field crops practiced until recently to achieve high yields required intensive tillage and application of other high-technology inputs. This concept, however, implies a number of problems, among which relationship between product quality and quantity are in the foreground, along with increase crop production, which shows an important ecological sustainability. Above all, farmers approach production in terms of cost effectiveness of applied system (Kisic et al., 2010).

Use of agricultural mechanization was considered the main factor contributing to total energy inputs in agricultural system. Tillage represents half of operations carried out annually in field. Consequently, there is a potential to reduce energy inputs and production costs by reducing tillage (Ozturk et al., 2006). Since land preparation for double-cropping systems requires timeliness, especially when a moldboard plow is used, reduced tillage, mainly NT systems, are becoming widespread.

Beneficial effects of the crop residue maintenance on soil surface include a reduction of soil erosion and runoff, an increase soil water conservation and soil aggregation, and a less use of fossil fuel is not direct effect of crop residue management (Nakamoto et al., 2006).

In order to combat soil loss and preserve soil moisture, a more attention has been focus on conservative tillage involving soil management practices that minimize disruption of soil structure (Samarajeewa et al., 2006). Soil compaction of agricultural soils is a global well recognized problem (Hamza and Anderson, 2005) due to deteriorated soil environment and adverse effects of intensive use of farm machinery on crop yield (Hamza et al., 2011). In China, subsoil compaction was also cause by inappropriate tillage, traffic and field operations on poor time (Zhang et al., 2006). Tillage is one of most effective ways to reduce soil compaction (Daniells, 2012).

Therefore, with selection of desired plant density, appropriate yield can be produced. Corn is among crops least tolerant to high plant population density. Roekel and Coulter (2011) determined a close relationship between maize yield and plant density. The studied hybrid produced maximal yield by a plant density of 81700 plants ha^{-1} or even higher.

On basis of their research, Berzsenyi and Lap (2005) have found that optimal plant density varied between 67483 and 70161 plants ha^{-1} regarding the average of the involved hybrids. Total dry matter increases from 6 to 40% when plant density increases from about 79000 to 165000 plants ha^{-1} in some studies (Turgut et al., 2005; Yilmaz et al., 2007).

According to Pepó and Sárvári (2013), maize is a plant with individual productivity; therefore, plant density determines yield significantly. This experiment was conduct to determine best plant density and tillage system in North of Iran.

MATERIALS AND METHODS

The study was conduct at Agricultural and Natural Resources Research Center Station of Dashte-Naz in MazandranIran for two years 2012-2013 (36°37' N, 53°11' E). The weather in this zone had an average temperature of 24.46°C per month. Receives average rainfall of 231.1 mm from May through October for two years. Weather condition in the experiment site are summarized (Tables 1 and 2).

The soil type was classified as clay loam, with pH 7.2. This experiment was laid out in strip-plot on randomized completely block design basis with four replications. Tillage systems were in three levels: 1. Plow and Disc system (PDS). 2. Disk system (DS) - 3. No tillage (NT). Another factor was plant density in four levels (70000, 80000, 90000 and 100000 plants ha^{-1}).

The previous crop at site was wheat. NPK fertilizers were applied according to yield potentials and soil test levels. N P K (200-100-100) fertilizer used was applied as urea, triple super phosphate and potassium sulfate according to soil test. Hand weeding was used to control weeds. Plants from each plot were harvested in an area of 9 m^2. Cultivar corn was a single cross hybrid (*Z. mays* L. cv. single cross 704) that was popular among growers in Iran. Ear height, plant height, ear length, row number, kernel number in row, ear diameter, wet and dry silage yield, wet and dry ear weight, wet and dry stem weight, wet and dry leaf weight were measured. The site was irrigated with water using a sprinkler irrigation system. Plants were cut at surface from central of four middle rows in plots (area of9 m^2).

Data were analyzed using the MSTAT-C procedure to develop the ANOVA for a split-split plot design. The Duncan's Multiple Range Test (DMRT) procedure was applied to make tests of simple and interaction effects by MSTAT-C, all differences reported are significant at P 0.05 unless otherwise stated.

Table 1. Weather condition in experiment site during corn growth stages (2012).

Variable	May	June	July	August	September	October
Minimum temp. (°C)	13.2	18.7	21.2	21.4	21.4	16.5
Maximum temp. (°C)	24.6	29.1	31.7	30.3	31.1	26.7
Evaporation (mm)	134.9	166.4	217.3	133.4	122.2	101.1
Precipitation (mm)	24.1	7.5	0	7.3	10.8	205.9

Table 2. Weather condition in experiment site during corn growth stages (2013).

Variable	May	June	July	August	September	October
Minimum temp. (°C)	15.7	20	23.1	22.5	22.8	15.2
Maximum temp. (°C)	27.2	30.8	31.8	33.8	32.4	26.0
Evaporation (mm)	151.7	165.2	183.8	208.5	158.2	93.2
Precipitation (mm)	4.4	136.1	5.2	8.8	1.2	50.9

Table 3. Means comparison of some traits of corn in three years.

Treatment	Dry forage yield (ton/h)	Dry stem weight (ton ha^{-1})	Dry ear weight (ton ha^{-1})	Dry leaf weight (ton ha^{-1})	Silage yield (ton ha^{-1})	Wet stem weight (ton ha^{-1})	Wet ear weight (ton ha^{-1})	Wet leaf weight (ton ha^{-1})
Tillage system								
Plow and Disck	17.02^{a}	7.11^{a}	2.06^{a}	7.85^{a}	52.40^{a}	22.23^{a}	21.23^{a}	8.94^{a}
Disck	16.31^{a}	6.50^{ab}	2.12^{a}	7.69^{a}	50.13^{a}	20.27^{ab}	20.71^{a}	9.16^{a}
No tillage	15.50^{a}	6.30^{b}	1.92^{a}	7.34^{a}	47.23^{a}	19.30^{b}	19.60^{a}	8.32^{a}
Density plant/ha								
70000	16.35^{b}	6.56^{b}	2.08^{ab}	7.70^{ab}	50.39^{b}	20.51^{b}	20.82^{ab}	9.06^{ab}
80000	15.33^{b}	6.31^{b}	1.89^{b}	7.12^{b}	47.20^{b}	19.72^{b}	19.25^{b}	8.24^{b}
90000	17.77^{a}	7.32^{a}	2.18^{a}	8.26^{a}	53.88^{a}	22.52^{a}	21.94^{a}	9.42^{a}
100000	15.66^{b}	6.29^{b}	1.96^{ab}	7.14^{ab}	48.21^{b}	19.66^{b}	20.04^{ab}	8.51^{ab}

Treatment	Ear height (cm)	Plant height (cm)	Ear length (cm)	Row number	Kernel number in row	Ear diameter (cm)
Tillage system						
Plow and Disk	87.31^{a}	193.3^{a}	17.59^{a}	13.66^{a}	27.04^{a}	4.268^{a}
Disk	89.21^{a}	195.9^{a}	17.80^{a}	13.52^{a}	25.52^{a}	4.35^{a}
No tillage	85.63^{a}	193.7^{a}	17.13^{a}	13.54^{a}	26.76^{a}	4.29^{a}
Density plant ha^{-1}						
70000	87.70^{a}	194.6^{a}	18.67^{a}	13.63^{a}	27.33^{a}	4.341^{a}
80000	85.28^{a}	191.1^{a}	16.85^{b}	13.42^{a}	25.91^{a}	4.246^{a}
90000	86.26^{a}	195.6^{a}	17.34^{b}	13.69^{a}	26.63^{a}	4.305^{a}
100000	90.29^{a}	196.0^{a}	17.17^{b}	13.57^{a}	25.90^{a}	4.330^{a}

Different letters in each column shows significant difference at 5% probability.

RESULTS AND DISCUSSION

Tillage system

Tillage system had significant effect on dry and wet stem weight at 0.05 probability level (Table 3). The highest dry stem weight was obtained in plow and disk (PDS) system with 7.11 tons ha^{-1}. Dry stem weight (6.50 tons ha^{-1}) in disk system (DS) had no significant difference with No-tillage system (NTS) with 6.30 t/ha (Table 3). Highest dry

Table 5. Means comparison of interaction of some traits of corn in two years.

Treatment Tillage systemX Density (plant ha^{-1})	Silage yield (ton ha^{-1})	Dry forage yield (ton ha^{-1})
Plow and Disk X70000	55.62[a]	18.09[a]
Plow and Disk X80000	48.88[bcd]	15.92[bc]
Plow and Disk X90000	54.38[ab]	17.65[ab]
Plow and Disk X100000	50.70[abcd]	16.44[abc]
Disk X70000	50.65[abcd]	16.44[abc]
Disk X80000	47.35[cd]	15.30[c]
Disk X90000	53.86[ab]	17.68[ab]
Disk X100000	48.67[bcd]	15.81[bc]
No tillage X70000	44.90[d]	14.53[c]
No tillage X80000	45.37[d]	14.75[c]
No tillage X90000	53.39[abc]	17.99[a]
No tillage X100000	45.25[d]	14.75[c]

Different letters in each column shows significant difference at 5% probability.

forage yield (17.02 tons ha^{-1}) was obtained in plow and disk (PDS) system with 17.02 tons ha^{-1} that had no significant difference with disk and No-tillage system with 16.31 and 15.50 tons ha^{-1} respectively (Table 3). The highest silage yield (52.40) was obtained in plow and disk (PDS) that had no significant difference with disk and No-tillage system with 50.13 and 47.23 tons ha^{-1}t/ha respectively (Table 3).

Plant density

Plant density had significant effect on dry forage yield, dry stem weight, dry ear weight, dry leaf weight, silage yield, stem yield, ear and leaf yield at 0.05 probability levels (Table 3).

The highest dry forage yield (17.77 tons ha^{-1}) and silage yield (53.88 tons ha^{-1}) were produced in 90000 plants ha^{-1}. Plant density had no significant difference in 70000, 80000 and 100000 densities on dry forage yield and silage yield (Table 3). With an increase of density from 70000 to 80000 plants ha^{-1}, ear length decreased. The highest dry stem (7.32 t/ha), dry ear (2.18 t/ha) and dry leaf (8.26 tons ha^{-1}) yield were obtained from the density of 90000 plants ha^{-1} (Table 3).

High silage yield (53.88 tons ha^{-1}) was achieved from ear (21.94 tons ha^{-1}), stem (22.52 tons ha^{-1}) and leaf (9.42 tons ha^{-1}) fresh weight had significant difference in ear, stem and leaf fresh weight. The effect of plant density had significant difference for silage yield (Table 3).

Shakarami and Partners (2009), in investigating three plant densities (7, 10 and 13 plants m^2) of corn recognized that highest grain yield, harvest index, number of grain row and number of grain ear was produced in 10 plant m^2 and the highest biological yield obtained from 13 plant m^2. Kisic et al. (2010), in the study of crop yield and plant density under different tillage systems found that the plant density and yields of maize, soybean, oilseed rape, winter wheat and spring barley point to the conclusion that high density crop (winter wheat, spring barley and oilseed rape) are suitable for growing under reduced tillage systems. Yield of low-density spring crops (maize and soybean) obtained under no tillage system are not satisfactory, especially in climatically extreme years.

Interaction between tillage system and plant density

The results indicated that most silage yield (55.62 tons ha^{-1}) was obtained from Plow and Disc system (PDS) in density of 70000 plants ha^{-1} that had no significant difference effects with No tillage system (NT) in density of 90000 plants ha^{-1} with silageyield of 53.39 tons ha^{-1}. The results also indicated that the most dry forage yield (18.09 tons ha^{-1}) was obtained from Disck system (PDS) in density of 70000 plants ha^{-1} that had not significant difference effects with No tillage system (NT) in density of 90000 plants ha^{-1} with silage yield of 17.99 tons ha^{-1} (Table 5).

Conflict of Interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Growth of eucalyptus seedlings irrigated with different wastewaters

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This study aimed to evaluate the growth of two species and one eucalyptus hybrid irrigated with different wastewaters. The experiment was carried out in a greenhouse in a completely randomized split-plot experimental design with three replications. The effluent included: Urban source, beef cattle slaughterhouse, poultry/swine slaughterhouse and soy processing/dairy plant from the wastewater treatment plants (WWTPs). In the subplot, the wastewater was diluted to the concentrations of 0, 25, 50, 75 and 100%. In the subplot, two species (*Eucalyptus citriodora* and *Eucalyptus urophylla*) and a eucalyptus hybrid (*Eucalyptus urophylla* x *Eucalyptus grandis*) were tested. The following physiological attributes were evaluated: mortality, root area, leaf area, stem diameter, plant height, green matter mass and dry matter weight. The results showed that the water from the beef cattle slaughterhouse WWTP, at 50% concentration, impaired growth of genotypes and promoted higher mortality values. As the concentrations of the four wastewater types increased, there was a significant variation for all characteristics except for: leaf area, plant height and dry matter weight with the soy processing/dairy WWTP water. The tested waters might be used in seedling irrigation of the two Eucalyptus plant species and the hybrid.

Key words: Sewage sludge, water reuse, seedling production.

INTRODUCTION

The planned use of wastewater residues from treatment plants (WWTP) are an important way to reduce or eliminate the discharge of nutrients and toxic elements into water bodies. In agriculture, this approach also ensures the supply of water and nutrients for the crops, reducing costs with the use of mineral fertilizers (Carey

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and Migliaccio, 2009; Qadir et al., 2010).

Eucalyptus plantations are expanding rapidly in tropical regions, with about 20 million hectares worldwide (Grant et al., 2012; Booth, 2013). The area of these fast-growing plantations in Brazil increased from 3.4 million hectares in 2005 to 5.6 million ha in 2014 (ABRAF, 2006; IBA, 2015), which represents about 25% of the total eucalyptus plantation area in the world and almost 70% of planted forests in Brazil.

Eucalyptus is the most planted forest species in reforestation programs in Brazil, usually it grows in low fertility soils where the rainfall quantity and distribution limit the survival and growth of other trees (Gama-Rodrigues et al., 2005). The use of fast-growing species, as eucalyptus, for timber production is concerned with the fixation (sequestering) of carbon (C), that is, the mobilization of CO_2 in the forest biomass, and especially in the timber product that has, as a rule, a long duration (Lima, 2005).

The objective of this work was to evaluate the physiological attributes of seedlings of two species and a hybrid of eucalyptus irrigated with four different wastewater.

MATERIALS AND METHODS

This study was conducted in a vegetation house at the Universidade de Rio Verde-GO, located in the city of Rio Verde, whose coordinates are: 50° 57’ 54’’ west longitude and 17° 47' 15'' south latitude, with an average altitude of 784 m.

Eucalyptus seeds were acquired at the Institute of Instituto de Pesquisa Florestais-IPEF-Piracicaba-SP and had an 80 to 90% germination rate. The seeds were sown in 50 cm^3 tubes filled with Bioplant® substrate and remained for 15 days in the nursery of the Comigo II Forest Company. During germination, they were irrigated by an automatic system with water coming from the company reservoir and covered with shade cloth (40% shading) until the thinning time, which occurred 30 days after emergence, leaving only one plant per tubet.

The phytosanitary control was carried out with the application of the fungicide Ridomil® and the insecticide Enguel®, according the criteria adopted by the Comigo Florestal Company.

The residuary waters were collected after their treatment from WWTP I - Urban source, WWTP II -Beef cattle slaughterhouse, WWTP III - Poultry/swine slaughterhouse and WWTP IV - Soy processing/dairy plant.

Irrigation with the wastewater treatment effluents was carried out with 2 manual sprinklers three times a day, at 7 a.m., 1 p.m. and 6 p.m. for 75 days. The WWTP wastewaters were diluted with distilled water at concentrations of 0, 25, 50, 75 and 100%.

The chemical composition of the wastewater was determined by the soil laboratory at the Universidade de Rio Verde, according to the methodology cited by Silva (1999). Two samples were taken, the first, on the day the water was captured at its origin and the second, seven days after the first collection, in order to verify changes in composition during the storage period in polyethylene bottles (Table 1). The electrical conductivity- EC and pH were determined by the laboratory of the WWTP and WTP of the BRF agribusiness using a Metrotem Micro Processor-Condutivity Meter-TDS apparatus and a Texto portable pH meter (Table 1).

The experiment was conducted in a completely randomized split plot design with three replications. In the main plot, it was allocated the wastewater type; WWTP I - Urban source, WWTP II -Beef cattle slaughterhouse, WWTP III - Poultry/swine slaughterhouse and WWTP IV - Soy processing/dairy plant, in a subplot, the wastewater was diluted to the concentrations of: 0, 25, 50, 75 and 100% and also in a subplot the two eucalyptus species (*Eucalyptus citriodora*, *Eucalyptus urofila*) and the eucalyptus hybrid (*Eucalyptus urophylla* x *Eucalyptus grandis*). Each subplot consisted of 20 eucalyptus seedlings and the 10 central plants were considered the useful area.

The volume of water supplied for each subplot presented variation according to crop need detected by the symptoms of water stress. The water levels used were 7.5, 10, 15 and 20 mm, equivalent to 2.25, 3, 4.5 and 6 liters per day, respectively until the end of the experiment, divided into three daily applications.

Seventy-five days after sowing, the plants were harvested and their physiological attributes were evaluated: plant mortality, root area, stem diameter, plant height, shoot green matter mass, leaf area and shoots dry matter mass of the eucalyptus seedlings according to the treatments.

Mortality (number of dead plants) was obtained by the difference between the count of living seedlings and amount of seedlings used in each subplot (20 plants). Root area (cm^2) was determined from the average values obtained from six plants. This was accomplished prior to separation of soil from root system by washing using running water. The material was stored in plastic bags with 30% alcohol in order to maintain hydration of real roots, and quantified using the "QuantROOT version 1.0" software (UFV). Plant leaf area (cm^2) was obtained from the mean values of six plants from each subplot determined by the digitalization of all leaves previously separated from the stem with scissors, and quantified using the "QuantROOT" software (UFV).

Stem diameter (cm) was obtained from average stem diameter of six plants from each subplot using a caliper, measured in the region of seedling collection. Plant height (cm) was obtained from the average height of six plants of each subplot, by measuring them from the collar until the last leaf using a millimeter ruler.

Fresh matter of the aerial part (g $plant^{-1}$) was obtained from the average weight of ten plants of each subplot. There was separation of the shoot at the collar region and subsequent weighing, using a digital scale with a precision of 0.001 g.

Dry matter of the aerial part (g $plant^{-1}$) was obtained from the average weight of ten plants of each subplot. There was a separation of the aerial part at the collar and the leaves, along with the stems, they were placed in paper bags and placed in an oven with forced-air circulation at 65°C, until constant weight. The material was then weighed on a 0.001 g digital scale.

Data of all the characteristics were subjected to statistical analysis. Regression by orthogonal polynomials was employed for the wastewater dilution factor, for the water types and species and they were analyzed by the Tukey test at 5% probability, using SISVAR statistical program (Ferreira, 2000).

RESULTS

The waste water from the beef cattle slaughterhouse WWTP presented the highest electrical conductivity, thus explaining the high mortality of plants irrigated at concentrations of 75 and 100%, respectively (Figure 1A).

The other types of wastewater also promoted significant plant mortality, a fact that must be associated with a gradual increase in nutrients as the wastewater concentration increased. The wastewater concentration increase was proportional to the number of dead plants with the use of all types of wastewaters (Figure 1A). The beef cattle slaughterhouse WWTP water stood out for

Table 1. Macronutrients and micronutrients contents in wastewaters and UniRV well water used in irrigation of eucalyptus seedlings in the various treatments. WWTP I (Urban source), WWTP II (beef cattle slaughterhouse), WWTP III (poultry and swine slaughterhouse), WWTP IV (soy processing and dairy plant).

Wastewater	Concentration	N	P	K	Ca	Mg	S	Fe	Mn	Cu	Zn	Electric conductivity	pH
		mg/L										µs/cm 25°C	
WWTP I	100%	14.50	1.25	15.1	14.61	3.62	20.58	0.321	0.022	0.001	0.001	577.00	8.43
	75%	10.90	0.95	11.7	16.75	3.85	15.91	0.241	0.017	0.001	0.001	464.00	8.47
	50%	7.24	0.64	8.35	18.90	4.08	11.25	0.161	0.012	0.001	0.001	399.00	7.30
	25%	3.62	0.33	4.98	21.04	4.30	6.58	0.081	0.006	0.001	0.001	285.00	7.90
	0%	0.00	0.03	1.60	23.18	4.53	1.91	N.D	N.D	N.D	N.D	N.D	N.D
WWTP II	100%	53.00	10.7	51.70	126.00	11.94	7.69	0.534	0.089	0.013	0.001	3.770	7.60
	75%	39.80	8.06	39.20	100.3	10.09	6.24	0.401	0.067	0.01	0.001	3.260	7.63
	50%	26.50	5.38	26.70	74.61	8.24	4.80	0.268	0.045	0.007	0.001	2.410	7.89
	25%	13.30	2.70	14.10	48.89	6.38	3.36	0.134	0.023	0.004	0.001	1.728	7.82
	0%	0.00	0.03	1.60	23.18	4.53	1.91	N.D	N.D	N.D	N.D	N.D	N.D
WWTP III	100%	22.00	5.54	54.00	37.97	4.97	41.72	5.972	0.254	0.001	0.001	1.245	7.21
	75%	16.50	4.16	40.90	34.27	4.86	31.77	4.479	0.191	0.001	0.001	953.00	7.13
	50%	11.00	2.78	27.80	30.58	4.75	21.81	2.987	0.128	0.001	0.001	764.00	7.04
	25%	5.49	1.40	14.70	26.88	4.64	11.86	1.494	0.064	0.001	0.001	503.00	7.33
	0%	0.00	0.03	1.60	23.18	4.53	1.91	N.D	N.D	N.D	N.D	N.D	N.D
WWTP IV	100%	1.17	3.19	20.00	27.66	2.37	222.00	0.19	0.001	0.001	0.001	999.00	9.86
	75%	0.88	2.40	15.40	26.54	2.91	167.00	0.143	0.001	0.001	0.001	890.00	10.00
	50%	0.58	1.61	10.80	25.42	3.45	111.9	0.096	0.001	0.001	0.001	710.00	9.77
	25%	0.29	0.82	6.20	24.30	3.99	56.92	0.048	0.001	0.001	0.001	491.00	8.40
FESURV WELL	0%	0.00	0.03	1.60	23.18	4.53	1.91	N.D	N.D	N.D	N.D	N.D	N.D

*ND: not shown.

presenting the death of almost all plants in the subplot when irrigated at the 100% concentration.

The root area, as a function of the wastewater concentration had linear positive behavior for the poultry/slaughterhouse WWTP and quadratic for the remaining treatments (Figure 1B). The wastewaters from the soy processing/dairy plant WWTP, beef cattle slaughterhouse WWTP and urban source WWTP, resulted in a maximum technical efficiency index of 75, 48, 67%, respectively. The inhibition of root growth can be linked to the high concentration of nutrients present in these treatments, with amounts of nutrients greater than required for eucalyptus seedlings. For the leaf area and stem diameter, it was observed that irrigation with most of the wastewaters promoted the highest average (Figure 1C and D) values, except the soy processing/dairy plant treatment, probably associated with its low N and P contents (Table 1).

The highest plant height (34.06 cm) was obtained for the urban source wastewater (Figure 1E) treatment, and the lowest average value was detected in plants irrigated with wastewater from soy processing/dairy plant and beef cattle slaughterhouse WWTPs.

For the shoot green and dry matter mass production, it was observed that the plants irrigated with wastewaters from the beef cattle slaughterhouse WWTP showed higher green and dry matter mass (Figure 1F and G). The leaf area, stem diameter, plant height and shoot green and dry matter mass presented similar behavior for the increasing wastewater concentrations. The WWTP-beef cattle slaughterhouse data were adjusted to a quadratic regression model and the remaining waters to positive linear model (Figure 1).

The WWTP-beef cattle slaughterhouse wastewater promoted the highest average values for leaf area (43%), stem diameter (34%), plant height (34%), shoot green matter mass (53%) and shoot dry matter mass (49%).

The mortality for both species and hybrid did not differ statistically from each other when subjected to treatments with waters from the soy processing and poultry/swine slaughterhouse. The wastewaters from WWTP-beef cattle slaughterhouse and WWTP-urban source presented significant differences between the species studied, showing that the hybrid was the most sensitive to both types of waters, whereas *E. citriodora* and *E. urofila* presented no significant differences between each other (Table 2).

The beef cattle slaughterhouse water presented higher plant mortality among the treatments, and this was

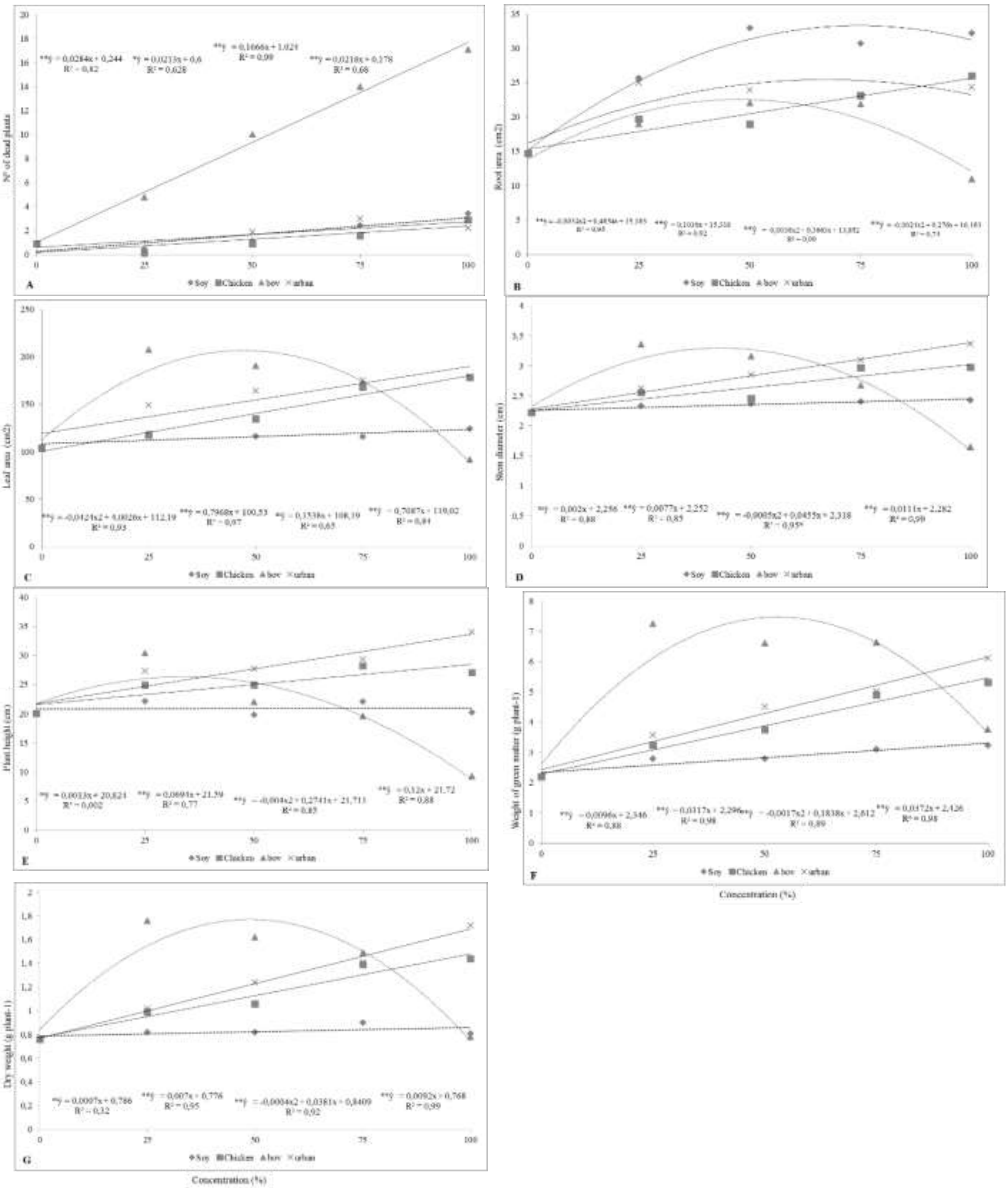

Figure 1. Number of dead plants, root area, leaf area, stem diameter, plant height, green matter mass, dry matter mass of seedlings of two eucalyptus species and a eucalyptus hybrid in function of irrigation with wastewater at different concentrations. **, *Significant at 1 and 5% probability, respectively.

Table 2. Mortality of plants and root area of seedlings of three eucalyptus genotypes within each wastewater type and behavior of the four types of water according to each species.

Genotype	WWTP I	WWTP II	WWTP III	WWTP IV
	Mortality (number of dead plants)			
Citriodora	0.87^{aA}	0.53^{aA}	8.27^{aB}	0.47^{aA}
Urofila	1.73^{abA}	1.33^{aA}	7.47^{aB}	1.53^{aA}
Urograndis	2.40^{bA}	1.93^{aA}	12.33^{bB}	3.00^{bA}
Root area (cm^2)				
Citriodora	24.47^{Ba}	21.59^{bAB}	16.85^{bC}	18.90^{bBC}
Urofila	28.98^{aA}	24.46^{aB}	19.60^{aC}	26.94^{aAB}
Urograndis	28.36^{aA}	15.46^{cC}	16.81^{bC}	20.99^{bB}
Leaf area (cm^2)				
Citriodora	123^{aA}	135^{abA}	128^{bA}	146^{aA}
Urofila	119^{aC}	157^{aB}	191^{aA}	158^{aB}
Urograndis	106^{aC}	129^{aBC}	141^{bAB}	160^{aA}
Stem diameter (cm)				
Citriodora	2.48^{AB}	2.79^{aAB}	2.37^{bB}	2.86^{aA}
Urofila	2.32^{aB}	2.63^{abAB}	2.91^{aA}	2.83^{aA}
Urograndis	2.27^{aB}	2.48^{bAB}	2.55^{bAB}	2.78^{aA}
Plant height (cm)				
Citriodora	22.85^{aB}	27.22^{aA}	19.21^{bC}	28.39^{abA}
Urofila	21.02^{abC}	26.51^{aAB}	23.67^{aBC}	28.68^{aA}
Urograndis	18.80^{bBC}	21.45^{bB}	18.00^{bC}	26.08^{bA}
Green matter mass (g $plant^{-1}$)				
Citriodora	3.40^{aB}	4.46^{aA}	4.29^{bA}	4.59^{aA}
Urofila	2.73^{abC}	3.99^{abB}	6.70^{aA}	4.33^{aB}
Urograndis	2.36^{bC}	$3.20b^{BC}$	4.89^{bA}	3.93^{aB}
Dry matter mass (g $plant^{-1}$)				
Citriodora	1.02^{aB}	1.36^{aA}	1.12^{bB}	1.39^{aA}
Urofila	0.77^{bC}	1.12^{bB}	1.61^{aA}	1.20^{abB}
Urograndis	0.67^{bC}	0.90^{cB}	1.13^{bA}	$1.10b^{AB}$

Means followed by the same lower case letter in the column and capital in the line do not differ by 5% with Tukey test.

associated with the chemical composition of the water (Table 2).

The root area of the three eucalyptus genotypes presented different behavior for all wastewater (Table 2). The species, E. urofila and the hybrid were more efficient when irrigated with soy processing/dairy plant water. The poultry/swine slaughterhouse water promoted larger root area for the species, *E. urofila*. The waters from the beef cattle slaughterhouse and urban source WWTPs had similar behavior.

The soy processing WWTP and the dairy WWTP promoted the formation of higher root area for the *E. citriodora,* species followed by the poultry/swine slaughter house WWTP, urban source WWTP and beef cattle slaughter house WWTP. The species *E. urofila* and the hybrid produced the highest mean root area when irrigated with treated wastewater from soy processing followed by the urban source WWTP, poultry slaughterhouse and beef cattle slaughterhouse WWTPs (Table 2). The wastewater from beef cattle slaughter-house proved to be the least efficient for root formation and the soy processing was the most efficient.

The leaf area of the three eucalyptus seedling genotypes was different, according to the water used for irrigation, and the *E. urofila* genotype presented the highest leaf area (Table 2). Seedlings of *E. urofila* irrigated with beef cattle slaughterhouse treated wastewater had the greatest leaf area. However, the *E. urograndis* eucalyptus hybrid seedlings had the highest leaf area when irrigated with wastewater from the urban source WWTP (Table 2).

It was observed that the stem diameter differed only for water coming from the beef cattle slaughterhouse, in which the species *E. urofila* was superior to others. When comparing the species within each type of water, there was a significant difference only for the *E. urofila* species and the hybrid presented the highest average when irrigated with poultry slaughterhouse, beef cattle slaughterhouse and urban source WWTP waters and the lowest average when irrigated with soy processing/dairy plant water (Table 2).

Plant height between species within each water type showed significant differences only for wastewater provided by the beef cattle slaughterhouse and poultry/swine slaughterhouse agro industries, where the *E. urofila* species was superior to the *E. citriodora* species and the *E. urograndis* hybrid. Comparing each species within each water type, it was observed that poultry/swine slaughterhouse and urban source WWTP waters were superior to the others for the species *E. citriodora.* The Soy processing water promoted the lowest plant height. The height of the *E. urofila* species irrigated with water from the urban source WWTP and poultry/swine slaughterhouse WWTP stood out, obtaining the highest average. The wastewater from urban source WWTP was shown to be superior for the *E. urograndis* hybrid plant height characteristic (Table 2).

The shoot green matter mass between species within each water type presented significant differences only for the water supplied by the beef cattle slaughterhouse. *E. citriodora* species stood out with the greatest mass weight dry for water originating from soy processing, poultry/swine slaughterhouse and urban source WWTPs. Otherwise, for the *E. urofila* species, height was the greatest for the beef cattle slaughterhouse WWTP water.

The shoot dry matter mass of *E. citriodora*, *E. urofila* and *E. urograndis* hybrid seedlings irrigated with wastewater from the soy processing/dairy plant WWTP were small. However, the seedlings irrigated with wastewater from the beef cattle slaughterhouse WWTP provided the highest mass for the *E. urofila* and *E. urograndis* hybrid species (Table 2).

Comparing the three eucalyptus genotypes as a function of the wastewaters types for the plant mortality, it was observed that irrigation with beef cattle slaughter-house water had differentiated behavior, obtaining the highest plant mortality, and this was associated with the chemical composition of this water (Table 1). Irrigation eucalyptus seedlings with wastewaters from the beef cattle slaughterhouse WWTP showed the highest eucalyptus seedlings mortality, independent of genotype evaluated.

DISCUSSION

The data demonstrate the possibility of using wastewater as an irrigation source for the eucalyptus seedlings. The application of the urban source WWTP effluent was significantly satisfactory for the growth of eucalyptus seedlings. These results are explained by many researchers, who claim that sewage effluents demonstrate a stimulating effect on the vegetative growth of the trees (Guo and Sims, 2000), for *Eucalyptus globules* (Bhati and Singh, 2003), for *Eucalyptus camaldulensis* (Ali et al., 2012) and for *Tipuana speciosa*.

Similar results are observed by Rebouças et al. (2010). These authors studied the growth of *Vigna unguiculata* (cowpea) under irrigation with treated domestic sewage wastewater, and observed an increase in the leaf area, number of leaves per plant and stem, leaf, root and total dry biomass.

According to Dechen and Nachtigall (2007), each nutrient present in the effluents has a specific role in plant metabolism and the imbalance between their proportions may cause disability or toxicity, limiting plant growth or even leading to their death.

Alves et al. (2009), studying leaf area irrigated with wastewater fertilized with nitrogen and phosphorus, observed that the application of the effluent did not affect the development of the cotton plants. The leaf area increased with increasing wastewater irrigation levels. The low concentration of N and P may impair the development of the plant aerial part and consequently present a leaf area decrease.

According to Missio et al. (2004), working with G*rápia,* showed an increase in the number of leaves and larger stem diameter in plants that received phosphorus fertilization, showing that this macronutrient is important for the development of these parts of the plant. According to Daniel et al. (1997) and Carneiro (1995), the increase in diameter of the stalk in general, is more important to indicate the seedling survivability in the field and should be more widely used in indications of fertilizer rates to be applied for seedling production.

Evaluating cotton crops irrigated with wastewater, Figueiredo et al. (2005), obtained positive results for plant height and Lemainski and Silva (2006), applying sewage sludge in corn, found better efficiency in the plant aerial part growth, when compared with mineral fertilizer. Augusto et al. (2003), evaluating the dry matter mass in forest species seedlings (*Croton floribundus* Spreng. (Capixingui) and *Copaifera langsdorffii* Desf. (Copaiba)) irrigated with wastewater, verified dry matter accumulation in the shoot as well as in the root system.

Figueiredo et al. (2005) and Azevedo and Oliveira (2005), working with wastewater on okra and cucumber crops, respectively, obtained similar results. Gomes et al. (2002) concluded that the stem diameter at the collar and plant height are the parameters most indicated for assessing the quality of eucalyptus seedlings.

According to Augusto et al. (2007), working with the production of *E. grandis* seedlings using wastewater in a continuous subirrigation system gave results that indicated that wastewater from sewage biological treatment systems can be used in nursery fertigation.

Conclusions

The tested waters might be used in seedling irrigation of the two *Eucalyptus* plant species and the hybrid. The use of wastewater WWTP as a source of water for irrigation of eucalyptus seedlings is an alternative viable for the final disposal of this waste, considering the fertilizer economy that this material can provide, in addition to the environmental benefit.

Conflict of interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Characteristics of soils under seasonally flooded wetlands (*oshanas*) in north-central Namibia

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Lowland wetlands generally have a high agricultural production potential and can be local hot-spots for biodiversity. Specific seasonal wetland system is largely distributed in north-central Namibia. Seasonal wetlands consist of seasonal river wetlands (locally known as *oshanas*). However, studies on soil fertility, salinity and sodicity in seasonal river wetlands are still limited in this area. The objective of this study was hence to investigate the soil fertility status of seasonal wetlands and evaluate their potential for agricultural production and consider sustainability of the land use system. Soil samples were collected from 102 different spots of the flood plain within 3 major seasonal rivers, and analyzed for their physico-chemical properties and salinity and sodicity. The findings for average soil organic carbon (1.94 g kg^{-1}) and average clay contents (102.3 g kg^{-1}) of seasonal rivers were drastically lower than the wetland of semi-arid Africa regions (organic carbon, 5.8 g kg^{-1}; clay contents, 340 g kg^{-1}), and organic carbon and clay content significantly ($p<0.05$) decreased at the lower part of each seasonal river. Most of the seasonal river soil's' electrical conductivity of saturated paste extract (ECe) and the sodium adsorption ratio of the saturated paste extract (SAR) were more than 4 dS m^{-1} and 13, respectively. However, there were large differences in electrical conductivity of saturated paste extract (ECe) and the sodium adsorption ratio of the saturated paste extract (SAR) values among the sampling spots. These findings suggest the high agricultural importance to improve the soil organic matter and clay contents, and land selection to avoid the strongly high saline-sodic soil sites in seasonal river.

Key words: Seasonal flooded wetland soil, soil fertility, soil salinity and sodicity, sustainable land use.

INTRODUCTION

Food crisis in Africa is far from over. Among other factors, improper cultivation, uncontrolled burning of vegetation and deforestation have been cited as causes of environmental degradation that result in the general

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critical food situation (Okigbo, 1990). Lowlands with wetlands, generally have a high agricultural production potential (Andriesse et al., 1994; Rodenburg et al., 2014). Lowland soils are usually fertile because they receive transported materials from adjacent uplands. Soil fertility characteristics of lowlands were reported in West Africa (Issaka et al., 1996; Buri et al., 1999; Abe et al., 2010).

Sub-Saharan Africa is endowed with diverse wetland types, including alluvial lowlands and small valley swamps. Wetlands are particularly important assets to rural people as they can fulfil many services (Turner et al., 2000). Apart from agricultural production, these ecosystems supply local communities with a range of goods, including hunting, fishing, forest and forage resources (Roberts, 1988; Scoones, 1991; Adams, 1993) and they are local hot-spots for biodiversity (Chapman et al., 2001).

North-central Namibia is a semi-arid area. The soil in this region is poor with low nutrients and classified as alkali soil or solonetz (Moller, 1997). Specific seasonal wetland system is largely distributed in north-central Namibia, which is called Cuvelai Seasonal Wetland System (CSWS). This seasonal wetland system consists of various types of wetlands; seasonal river wetlands (locally known as *oshana*/*oshana*s), small seasonal ponds and large pans (Mendelsohn et al., 2000). The *oshanas* occupy a large area of the wetland system during the rainy season by receiving local rainfall and flood water from Angola. The *oshana* water gently streams from north to south during December to May. Salinity and sodicity problems are common in low-rainfall regions (Brady and Weil, 2008). Sand and clay mixture with sodic properties are dominant in *oshanas* in north-central Namibia, because sodium and other salts are carried by flood water and accumulate in lowlands (Mendelsohn et al., 2000).

A lot of wetlands in the world have in the past been overutilized, for agricultural expansion and intensification, because with increasing population growth there is a strong need for livelihood support and food security (Halsema and Wood, 2008). Such changes have often led to a gradual degradation of wetland ecosystems and substantial loss in food security (Halsema and Wood, 2008). Therefore, human development and utilisation of wetlands should consider maintenance and sustainability of ecosystems (Ramsar Convention Secretariat, 2007).

There are a few studies conducted so far on physicochemical properties of soils in North-central Namibia (Turner et al., 2014; Hillyer et al., 2006). However, wide area studies on soil fertility, salinity and sodicity in seasonal wetlands, such as *oshanas*, are still limited. Assessing the chemical and physical properties of these soils is necessary to gain information on how to sustain land use, maintain natural resources and adapt to the new environment. The objective of this study was to investigate the soil fertility status of *oshanas* and to evaluate the potential of agricultural production and consider sustainability of the land use system.

MATERIALS AND METHODS

Study area

The study focused on the CSWS in North-central Namibia, which is an ancient depression filled with sediments. During the rainy season, the flood water forms seasonal wetlands which form part of the huge CSWS, which is part of the drainage system originating from southern Angola. Mean annual rainfall in the CSWS ranges from 91.4 to 822.2 mm with an average monthly temperature from a minimum of 9.1°C in June to a maximum of 36.5°C in October, from 2003 to 2015 (a nearest public meteorological station). The vegetation can be broadly classified into five major associations; namely, mixed woodland of the deep aeolian sands, the Palm tree savanna, Mopane woodland and Mopane savanna, Sclerocarya-Ficus savanna, and Various scrub Mopane-Acacia (Moller, 1997). The soils are classified into three major groups: Cambic Arenosols, Eutric Cambisols, and Haplic Calcisols (Mendelsohn et al., 2002). Most of the soils in this region are classified as alkali soil or solonetz (Moller, 1997). Many people benefit from the seasonal wetlands. Fishing and grazing are common practices in the wetland area.

Soil sampling

Soil samples were collected during 2013 to 2014 from 102 different spots of the flood plain. The three *oshana*s are about 40 km apart along the Angolan border, narrowing to around 20 km distance in the middle, and later converging at Lake Oponono. Each sampling spots along each *oshana* is approximately located 5 km further from the next one. At the soil sampling points, the dominant vegetation were few grass fallow, the slope was gentle (less than 1%), and the average ground water level was less than 5 m. The starting point was near the border of Angola and the end point was at Lake Oponono (Figure 1).

At each spot, 3 sub-samples were collected along topographical setting (lower, middle upper) from 0-15 cm depth and bulked together and a composite sample was used for chemical/physical analysis. Fifteen different soil samples were also collected from upland field (cropland) as a control. Sampling was made with steel cylinder core sampler; with a volume of 100 cm^3. Soil samples were then air-dried and sieved through a 2 mm sieve for physicochemical analysis.

Laboratory analysis

The glass electrode method was used to determine soil pH in water (soil: H_2O, 1:2.5), and here after shown as pH (H_2O). Organic carbon content was measured by the Walkley Black method. Total nitrogen content was measured by the modified Kjeldahl method (salicylic acid added to the sulphuric acid). Available phosphorus (P) was extracted by the Olsen method followed by colorimetric measurement using an Ultraviolet-Visible (UV/VIS) spectro-photometer (Spectrophotometer; UV mini 1240, Shimadzu Corporation, Kyoto, Japan). Exchangeable calcium (Ca), magnesium (Mg), and potassium (K) were extracted from the soil with 1 mol L^{-1} neutral ammonium acetate, and were subsequently determined using an Inductively Coupled Plasma-Optical Emission Spectrometer (ICP-OES; Optima 7000 DV, Perkin Elmer Inc., U.S.A.). The pH, the electrical conductivity (ECe) and the concentrations of soil Ca, K, Mg and Na were determined from the extract from saturated paste of the soil samples and were

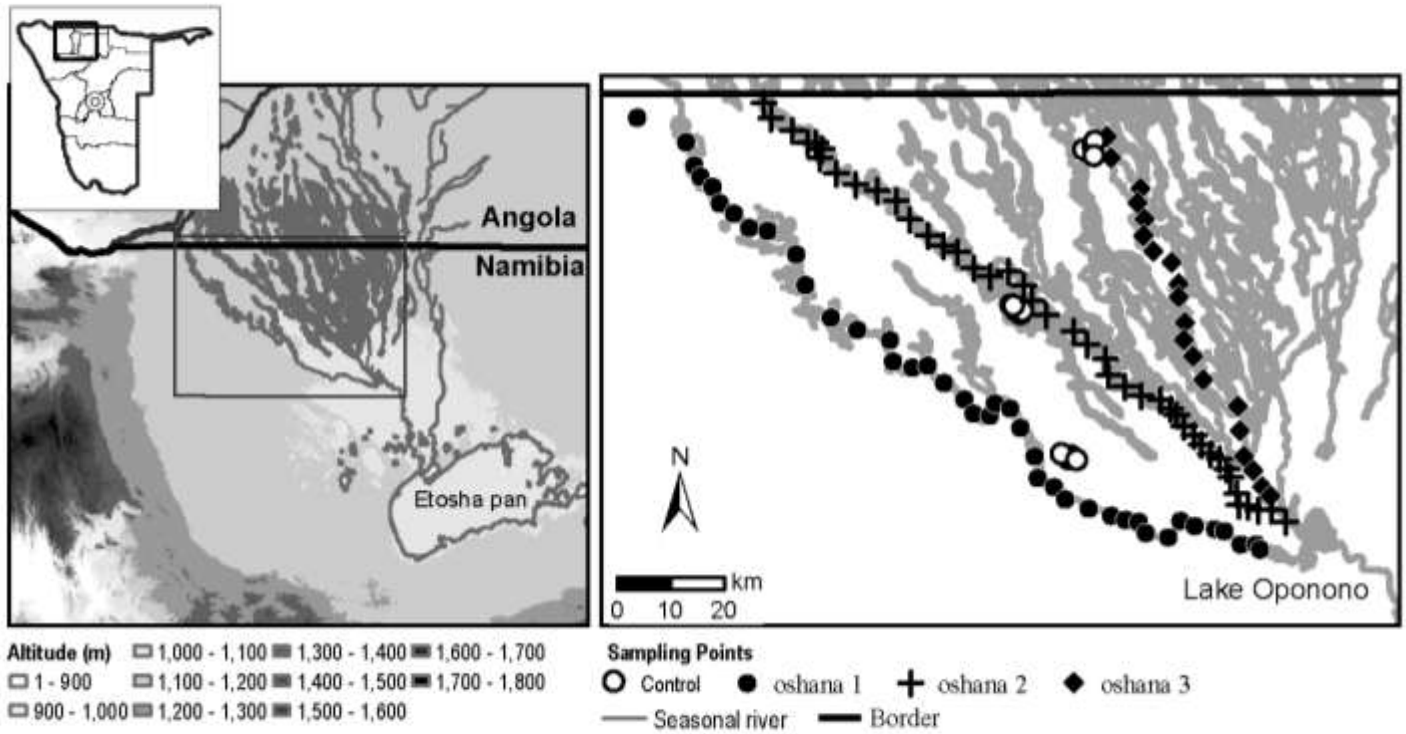

Figure 1. Sampling spots from 3 major *oshanas.* (*oshana* 1= 40, *oshana* 2= 42, *oshana* 3= 20).

subsequently determined using a pH-mV and conductivity meter (MultiLab 540; WTW Wissenschaftlich- Technische Werkstätten GmbH Weilheim i. OB, Germany), and an ICP (ICP-OES; Optima 7000 DV, Perkin Elmer Inc., U.S.A.). Soil salinity was expressed through the soil electrical conductivity of saturated paste extract (ECe) analysis. The adsorption of sodium by the soil was expressed by the sodium adsorption ratio of the saturated paste extract (SAR). This ratio was used as an indicator of sodicity, and was defined as

$$SAR = Na^+ / \sqrt{(Ca^{2+} + Mg^{2+})/2} \quad (1)$$

Soil particles were determined using the pipette method.

Data analysis

All results were reported as the mean ± standard error. One-way ANOVA tests were used to compare the soil physicochemical properties between different land use conditions. Pearson's correlation coefficients were used to compare soil fertility parameters originating from *oshana* soils. All statistical analyses were performed using Excel Statistics Version 2015 software (Social Survey Research Information Co., Ltd., Japan).

RESULTS

General soil fertility

The results of physico-chemical properties that contribute to the general soil fertility of *oshana* soils are shown in Figure 2. Soil pH (H_2O) in *oshanas* ranged from 6.2 to 10.2 with a mean of 7.61. Most *oshana* soils were neutral, but some were alkaline, where the pH was more than 8.5. Organic C and total N ranged from 0.38 to 5.05 g kg^{-1} and 0.10 to 0.60 g kg^{-1}; respectively, with a mean of 1.95 and 0.27 g kg^{-1}, respectively. Clay content in *oshanas* was 0 to 337.6 g kg^{-1} with a mean of 103.3 g kg^{-1}. Those results show that *oshana* soils are sandy with little organic matter. The means of exchangeable Ca, Mg, K, and Na in *oshanas* were 1.49, 0.41, 0.45, and 4.88 $cmol_c$ kg^{-1}, respectively. Sodium was the cation which occupied the greater part of the exchange sites. Available P in *oshanas* ranged from 0.08 to 17.40 mg kg^{-1} with a mean of 3.49 mg kg^{-1}.

Soil chemical properties in *oshanas* varied widely. Comparison of each *oshana*, showed that exchangeable K and Na, silt contents in *oshana*1 were significantly higher than those of *oshana* 2 and 3. Exchangeable Ca and available P were significantly lower for the *oshana* soils than the croplands. Comparing *oshanas* and croplands, exchangeable K and Na, and silt and clay contents were significantly higher in *oshana* 1 than the croplands. Exchangeable Ca and available P were significantly lower in *oshanas* than the croplands.

Comparing *oshanas* and wetlands in other regions, organic C, total N, exchangeable Ca and Mg in the *oshana* soils were lower than those of the flood plains and the inland valleys in West Africa (Figure 2). C/N ratio, exchangeable K, and available P were stable among the regions. Exchangeable Na was higher in *oshana* soils

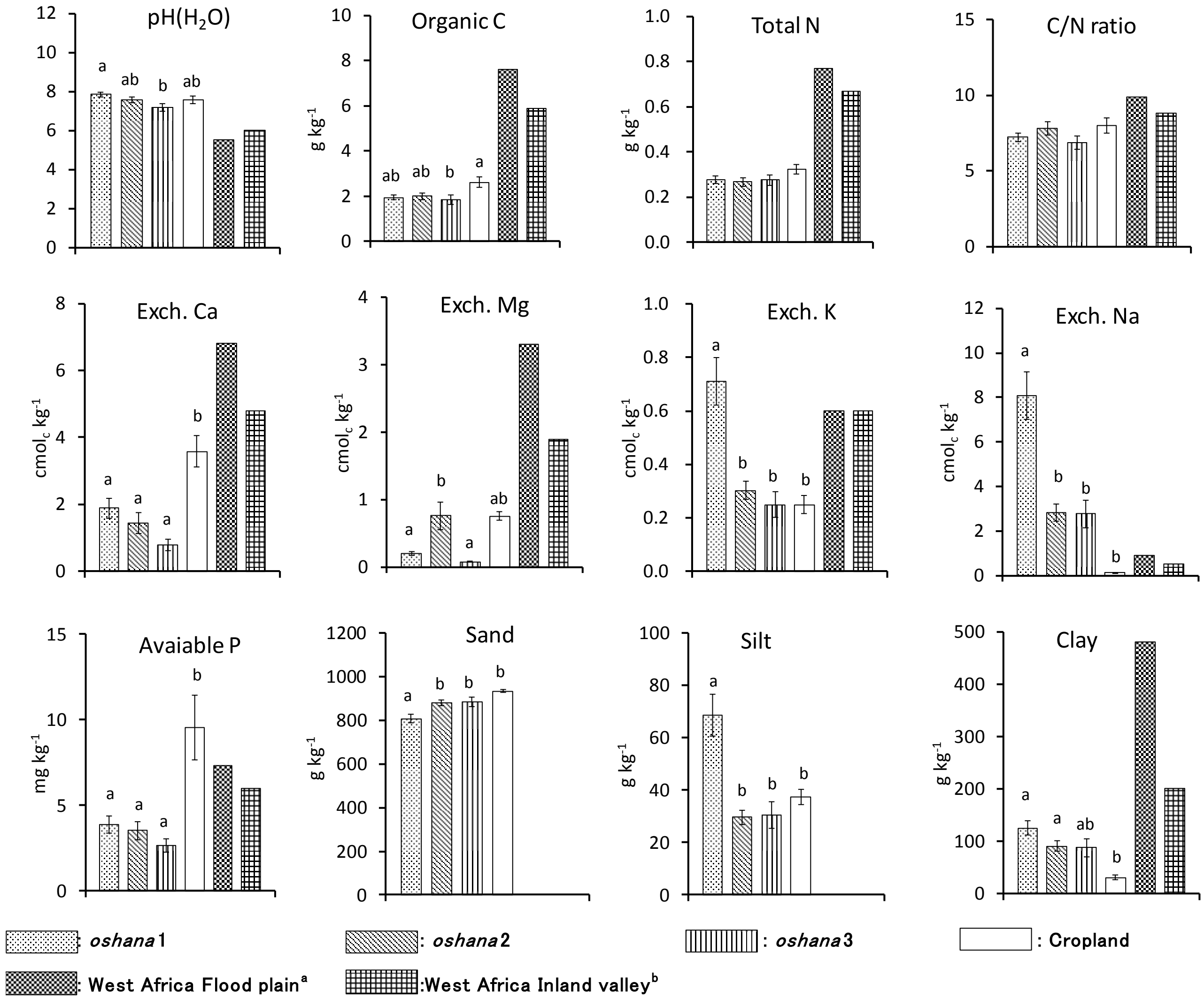

Figure 2. The physicochemical properties of *oshana* and other lowlands in West Africa. Error bears represent the standard error of mean. Different letters indicate significant differences between treatments at 5% significance level using Tukey-Kramer test. [a]Buri et al. (1999) and [b]Issaka et al. (1996). pH, glass electrode method with 1:1 soil:water extraction; organic C and total N, dry combustion method; available P, Bray-2 method; exchangeable cations, neutral ammonium acetate extraction method; clay content, pipette method.

than that of the flood plains and the inland valleys in West Africa.

Soil salinity and sodicity

Some characteristics of soil salinity and sodicity of the *oshanas* are shown in Figure 3. Based on determinations from saturated extract solution, the $pH_{saturated}$ of *oshanas* ranged from 4.70 (acidic) to 8.20 (alkaline) with a mean of 6.55. The ECe and SAR in *oshanas* soil ranged from 0.11 to 32.20 ds m^{-1} and 0.50 to 155.09 with a mean of 6.55 ds m^{-1} and 39.84, respectively. In principle, soils with ECe and SAR of more than 4 and 13 are judged as saline and sodic soils, respectively (Soil Science Society of America, 1997). The mean values for Ca, Mg, K, and Na determined from saturated extract solution were 1.92, 2.08, 1.29, and 54.06 $mmol_c\ l^{-1}$. There was a tendency that sodium was very high. ECe, Ca, Mg, Na and SAR for the *oshana* 1 soil were significantly higher than the cropland and *oshana* 2 and 3 soils. However, the soil properties of the cropland and *oshanas* 2 and 3 were not significantly different from each other.

Dynamics of soil physicochemical properties in seasonal stream wetland

Organic carbon was significantly correlated to Total N, Exch. K, Ca, Mg, and Clay (Table 1). Clay was

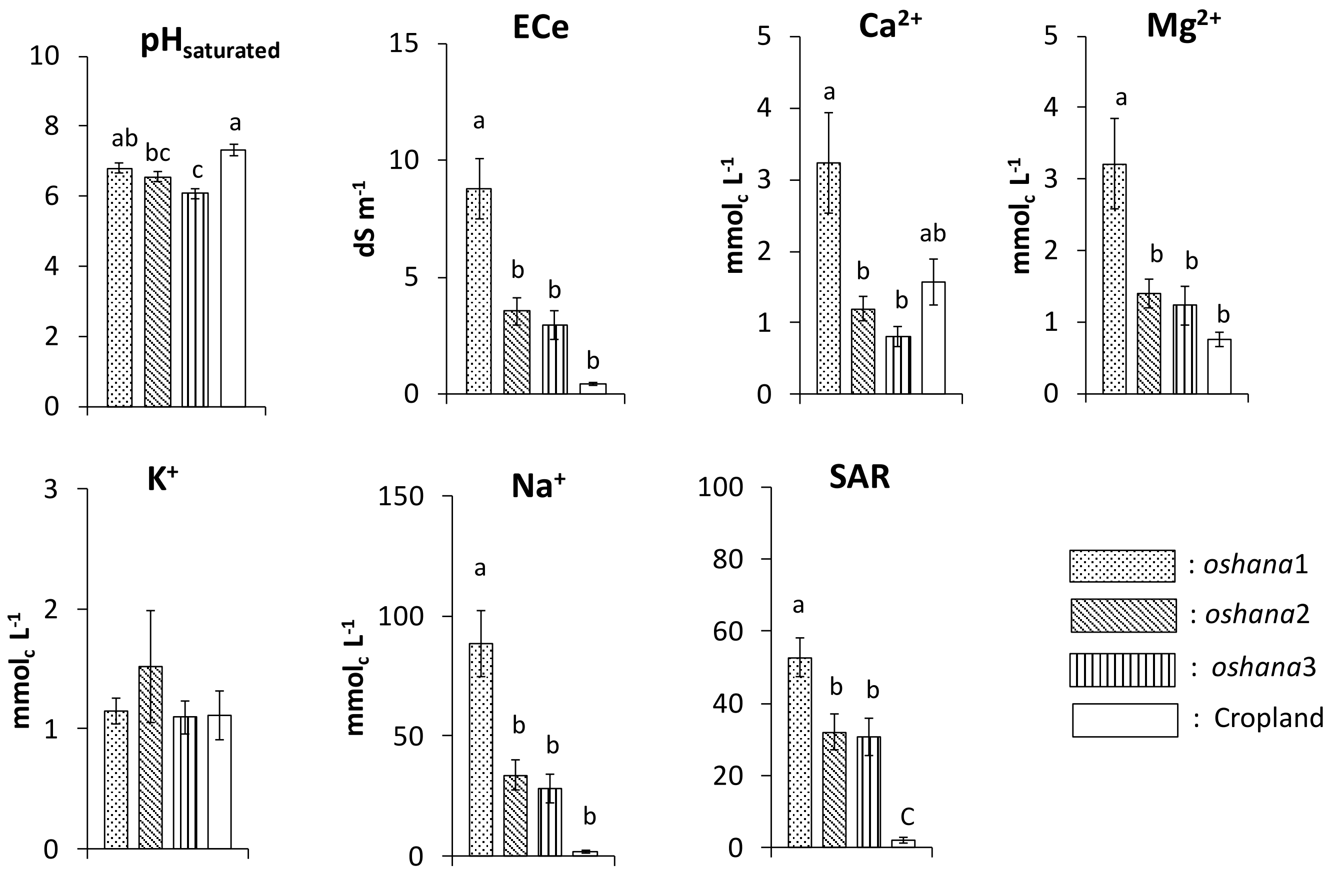

Figure 3. Soil salinity and sodicity of croplands and *oshanas.* Error bears represent the standard error of mean. Different letters indicate significant differences between treatments at 5 % significance level using Tukey-Kramer test.

Table 1. Correlation matrix of selected physicochemical parameters.

	pH (H_2O)	Org. C	Total N	Exch. Ca	Exch. Mg	Exch. K	Exch. Na	Av. P	Clay
pH (H_2O)	1.00								
Org. C	-0.21*	1.00							
Total N	-0.10	0.64**	1.00						
Exch. Ca	0.11	0.51**	0.66**	1.00					
Exch. Mg	-0.09	0.38**	0.56**	0.63**	1.00				
Exch. K	0.02	0.46**	0.56**	0.57**	0.23*	1.00			
Exch. Na	0.17	0.18	0.28**	0.20*	-0.04	0.80**	1.00		
Av. P	0.14	0.17	0.34**	0.36**	0.36**	0.51**	0.44**	1.00	
Clay	-0.01	0.60**	0.72**	0.73**	0.41**	0.78**	0.53**	0.46**	1.00

*p<0.05, **p<0.01 (n=102)

significantly correlated to all soil nutrients that were determined. Therefore, Organic C and clay contents appear to have an important bearing in soil fertility of *oshana* soils.

Dynamics of organic C and clay contents from upper to lower stream in *oshana* 1, 2, and 3 are shown in Figure 4. Organic carbon and clay content significantly decreased at the lower river in *oshana* 1 and 2. Organic carbon and clay content in *oshana* 3 did not so much decrease at the lower stream and were not significantly dependent on stream position. Organic carbon in *oshana* 1 and 2 was higher than that in *oshana* 3. Clay content in upper stream of *oshana* 1 was higher than that in *oshana* 2 and 3.

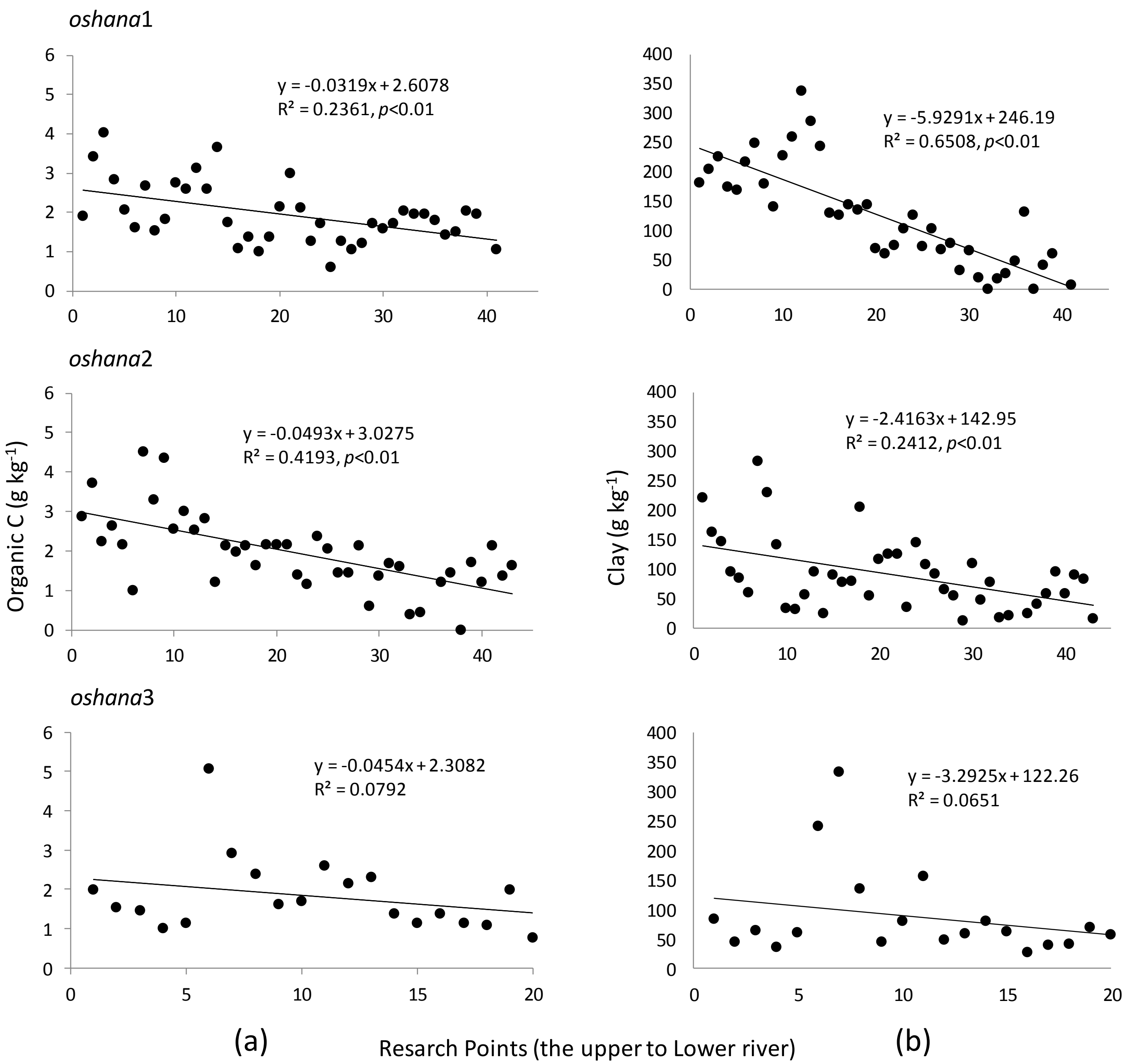

Figure 4. Simple liner regression between (a) organic carbon and research points, (b) clay contents and research points from 3 major *oshanas.* (*oshana* 1= 40, *oshana* 2= 42, *oshana* 3= 20).

ECe and SAR quality were not dependent on stream position (Figure 5). ECe and SAR were less than 10 ds m^{-1} and 50 in most of sampling points, respectively, although some points had strongly high values. In general, ECe and SAR in *oshana* 1 were higher than that in *oshana* 2 and 3.

DISCUSSION

General soil fertility conditions of *oshanas*

Since on the average most of the *oshana* soils were neutral to slightly alkaline, the soil reaction conditions in this region was favorable for producing a wide range of crops. However, the organic carbon and nitrogen contents were much below average that unless organic matter or fertilizer amendments were added, these soils could be regarded as extremely poor in soil fertility. The situation was even more compounded by the very low contents of phosphorus and exchangeable cations, which rendered these soils as unproductive. Additionally, the clay content of the *oshanas* was so low that it would be difficult for these soils to retain sufficient plant nutrients under the present natural condition.

According to results, most *oshana* soils can be

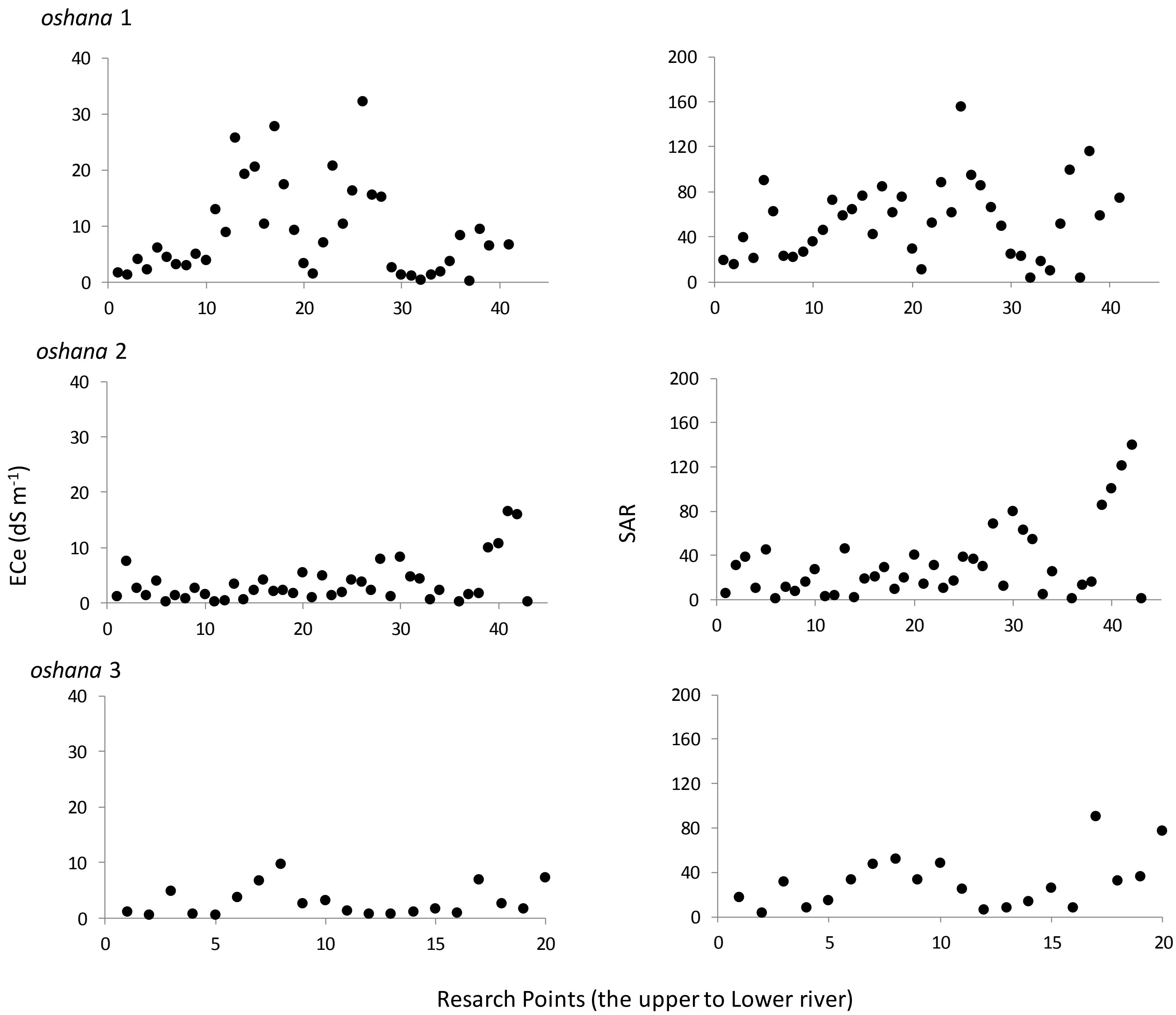

Figure 5. ECe and SAR quality of the upper to lower stream of 3 major *oshanas.* (*oshana* 1= 40, *oshana* 2= 42, *oshana* 3= 20).

regarded as saline and sodic. In a few instances lower ECe and SAR values have been observed. From this research one can derive that soil salinity and sodicity properties in *oshanas* vary widely. Among the *oshanas*, exchangeable K and Na, silt, ECe and SAR in *oshana*1 were significantly higher than those of *oshana* 2 and 3 (Figures 2 and 3). According to Mendelson et al. (2000), there is clay distribution in the west to south part of the CSWS, close to *oshana* 1 compared to the other *oshanas*. The presence of clay in the vicinity can hence play a role in enriching the fertility status of oshana 1 over the other *oshanas*. Since most of the *oshana* soils had high Na^+ ions on the exchange spots and mean pH of 7.7, they could be classified as saline-sodic soils. Saline-sodic soils exhibit physical conditions intermediate between those of saline soils and sodic soils.

There are some similarities in lowland wetlands in West Africa and *oshanas*. Lowlands in West Africa consist of inland valleys and flood plains. Inland valleys can be defined as seasonally flooded wetlands comprising valley bottoms (fluvial) and hydromorphic fringes (phreatic) but excluding river flood plains (Rodenburg et al., 2014). Inland valley is a swamp and the position is the upper reach of river systems in the gentle slope of a peneplain.

In the seasonal regimes of rivers in semi-arid Africa high water levels cause extensive inundation. The area, flooded then by the rivers can be reduced to pools of water separated by dry land (Adams, 1993). In West Africa, flood plains are distributed at the Senegal River Delta, the Inner Niger Delta, the lake Chad Basin (Buij and Croes, 2013). Those lowlands, inland valleys and flood plains are seasonal wetlands and of low soil fertility (Issaka et al., 1996; Buri et al., 1999; Abe et al., 2006).

Compared to lowland wetlands of West Africa, the *oshanas* in north-central Namibia happen to be much less fertile due to lower contents of the essential plant nutrients. The West African lowland wetlands in turn have lower fertility status compared to other tropical wetlands. Therefore, this indicates how poor the *oshanas* of north-central Namibia.

Even the cropland soils which appeared to have better soil fertility than the *oshanas* (Figure 2), when cultivated with pearl millet were reported to yield only between 0.1 to 0.5 ton per hectare (Shifiona et al. 2016). Through personal communication with some farmers, it was recognized that yields of maize, sorghum and other crops also appeared to be generally low. The situation therefore calls for the need of some strategic fertility options such as inclusion of legumes in the crop rotation, proper soil management practices such as mulching, and organic matter additions to improve the fertility condition of these soils.

Characteristics of soil physicochemical properties

Oshana soils generally were sandy with low organic matter content, and these soils were classified as Arenosols. The results of our study indicated that organic C and clay contents were major indicators of soil fertility (Table 1). Soil organic matter and clay influence soil physicochemical properties. Soil organic matter reduces the plasticity and cohesion of soils, and increases water holding capacity (Brady and Weil, 2008). Soil organic matter and clay hold nutrient cations (Brady and Weil, 2008). These results suggested that *oshana* soils are easily affected by environmental changes.

Organic C in the *oshana* soils was lower than that of the flood plains and the inland valleys in West Africa (Figure 2). Most of the particle size was sand, and the clay content was very low in *oshana* soils. The other soil nutrients in *oshanas* were lower than in West Africa except for exchangeable K (Figure 3). Soil fertility in the West African lowlands is much less than other tropical regions (Abe et al., 2010). These results indicate that soil fertility of *oshanas* is lower than other tropical wetlands in the world.

Organic C and clay content decreased with topography at the lower river (Figure 4). In the northern part of this study area shrub vegetation dominated while in the south part it was mainly grass vegetation (Mendelsohn, 2000). The shrub vegetation was higher in biomass than grass lands. The grasslands in this study area may face high grazing stress; thereby resulting in low organic matter from the grasses. Organic C content in this study decreased at lower positions of the *oshanas* (Figure 4). Cambisols and Calcisols covered the northern part of the study area with relatively higher clay contents than the Arenosols which covered the southern part of the study area (Mendelsohn et al., 2002). Arenosols had sandy texture, and contained more sand than Cambisols and Calcisols. Therefore, clay content decreased at lower stream (Figure 4). Organic C and clay contents in the *oshana* soils varied widely among the sampling points (Figure 2 and 4). The correlation of clay and organic matter was very high (Table 1). Shrub planting increased the quantity of silts + clay content and organic matter (Rathore et al., 2014). There were a lot of soil organic matter and clay contents at the spots where there was high plant biomass. Clay contents in *oshanas* were significantly higher than that of cropland field (Figure 1). The clay is transported through runoff from the surrounding uplands to inland valley in West Africa (Ogban and Babalola, 2003). Our results suggested that clay materials are eroded from upland fields and flow into *oshana*.

Soil organic matter and clay content can protect soil erosion and maintain soil fertility. Soil organic C and clay contents were drastically low in *oshanas* (Figure 4), and hence the soil was vulnerable to erosion. However, those organic C and clay contents varied widely in topographical positions. Therefore, it is suggested that major agricultural activities should focus on selected high organic C and clay content positions for sustainable land use. Maintenance and improvement of soil organic matter content could result in sustainable food production in Sub-Sahara Africa. Seasonal wetlands (dambos) are cultivated in southern Africa by applying cow manure as organic amendment to sustain crop yields (Nyamadzawo et al., 2014). Applying plant residues or animal manure increases soil organic carbon in Vertisols (Hua et al., 2014). It is also useful to prevent clay removal by erosion. In addition to increasing organic matter, organic amendments could reduce the effect of salts and alkalinity by releasing organic acids. Saline sodic conditions may equally affect ground water quality in the long run. Clay content is an important factor for land productivity and drought tolerance (He et al., 2014). The clay content can be reduced by erosion (Rejman et al., 2014). Applying biochar prevents erosion due to rainfall in sandy clay loam soils (Sadeghi et al., 2016).

Soil salinity and sodicity

ECe, Na^+, Mg^{2+}, and SAR of *oshana* 1 soils were significantly higher than the cropland (Figure 3). Especially, Na^+ content was drastically higher in the *oshana* 1 soil than the cropland soil. However, ECe of *oshana* 2 and 3 soils were not significantly different from those of croplands. The average of ECe and SAR in the cropland were 0.42ds m^{-1} and 2.08, respectively (Figure 3). Those values did not pose any problem of salinity and sodicity on the farmlands. The likely reason for this is because croplands are situated in the upper slope positions, whereas *oshanas* are found in lower slope positions and sodium is dissolved by ground water and moved to lower slope positions. Mendelsohn et al. (2000) reported that total dissolved solid in ground water is above 2600 mg l^{-1} under a lot of sites in north-central region.

ECe and SAR quality were not affected by stream position (Figure 5). ECe and SAR were less than 10 ds m^{-1} and 50; respectively, in most of the sampling points. However, some points had strongly higher values. Saline-sodic soil affects plant growth and contributes to soil structure deterioration. Increased osmotic pressure of soil water, which impedes its uptake by the roots, and nutrient imbalances, which in turn lead to toxicities and differences, are the major causes for the adverse effects of salinity and sodicity on plant growth. ECe was significantly correlated with SAR (r = 0.74, $p < 0.01$). ECe is good indicator of agricultural site selection. It is imperative to manage the saline-sodic conditions in the *oshana* soils of the CSWS for improved crop productivity. In a seasonal wetland in California, the river salt loads were managed and the water and salinity mass balances were regularly monitored (Quinn et al. 2010).

Conclusions

Soil fertility of *oshanas* is generally low. Especially, soil organic C and clay contents are drastically lower than other wetlands in other tropical regions. Most *oshana* soils are saline-sodic soils. However, the values of salinity and sodicity are very different at each research points. Land selection is very important, and agricultural land should avoid the strongly saline and sodic sites. *Oshana* soils are very vulnerable to erosion and are easily prone to salinity and sodicity. Such changes have led to degradation of wetland ecosystems and substantial loss of crops; thereby threatening food security. Therefore, it is important to adjust and sustain wetland ecosystems, such as *oshana* ecosystems. In order to prevent erosion and problems related to saline-sodic conditions in the agricultural land, it is important to keep natural vegetation in some areas.

Conflict of Interests

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

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Full Length Research Paper

Improved production systems for common bean on Phaeozem soil in South-Central Uganda

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Common bean (*Phaseolus vulgaris* L.) is the most important grain legume in Uganda. Beans managed under conventional systems range in yield from 500 to 800 kg ha^{-1}, with a yield gap of about 75%. The objective of this study was to compare the productivity and net profitability of four bean cultivars grown under three management systems on Phaeozem soil (Mollisol) in Masaka District, Uganda. The experimental design was a randomized incomplete block in a split-plot arrangement. Management system was the whole-plot factor and included the Conventional Farmer (CFS), Improved Farmer (IFS), and High Input systems (HIS). Management systems differed for seed fungicide treatment (no vs. yes), seeding density (10 vs. 20 seed m^{-2}), plant configuration (scatter vs. rows), fertilizer applications (P, K, Ca, and Mg), rhizobium inoculation (no vs. yes), pesticide applications (no vs. yes), and frequency and timing of weeding. Subplots were four common bean cultivars selected for varying resistance to foliar pathogens. Increasing management intensity and planting cultivars tolerant to common bean diseases improved bean grain yield. Mean grain yield was greater in HIS than IFS and CFS. For all management systems, disease resistant NABE 14 produced more grain yield than NABE 15, K132, and NABE 4. The HIS with NABE 14 produced the most grain (1772 kg ha^{-1}), most likely due to its greater resistance to angular leaf spot, bean common mosaic virus, and root rot. The economic return to labor and management was greatest for HIS with NABE 14 ($559 ha^{-1}). Many management system × cultivar combinations resulted in a net loss in the 2015A season, except for NABE 14. Increased yields and profitability are obtainable when utilizing NABE 14 or other disease resistant varieties under improved management practices with increased inputs.

Key words: *Phaseolus vulgaris*, soil fertility, crop management systems, improved cultivars, profitability.

INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is the most important grain legume in Uganda (Beebe et al., 2014) and is produced primarily by smallholder farmers (Ugen et al., 2002). About two decades ago, per capita bean consumption in Uganda exceeded 50 kg year^{-1} in some regions (Wortmann et al., 1998a), but more recent countrywide consumption averages about 11 to 16 kg person^{-1} year^{-1} (Broughton et al., 2003). Although, the per capita consumption has decreased, the total demand is still increasing due to population growth (Kilimo Trust, 2012).

Bean yields and soil quality have declined in Uganda over the past two decades (Bekunda et al., 2002), partly due to increased cropping intensity and lack of longer-term bush fallow (Chianu et al., 2011). Beans managed under conventional systems are only producing 500 to 800 kg ha^{-1}, on average, despite having a potential yield of up to 2500 kg ha^{-1} (Bekunda et al., 2002; Broughton et al., 2003). Bean production in Uganda is low due to numerous constraints including poor agronomic practices, soil infertility, lack of seed from improved cultivars, moisture stress, weed competition, and damage caused by pests and diseases (Sinclair and Vadez, 2012). Many farmers are currently looking for improved management systems to increase bean yields; however, there has been little research conducted on management systems that alleviate the aforementioned constraints. Agronomic practices that maximize bean production are not commonly used in Uganda even though some agronomic practices such as planting in rows and more frequent weeding can be implemented with minimal or no additional capital investment.

Fertilizer additions can overcome specific nutrient deficiencies, but fertilizers are expensive investments in sub-Saharan Africa, including rural Uganda, and most farmers use low levels or no fertilizer at all (Bekunda et al., 2002; Chianu et al., 2011; Lunze et al., 2012), contributing to further nutrient depletion of soil. Fertilizing bean can increase root growth providing improved access to soil water (Beebe et al., 2014) and nutrients. Soil testing of available nutrients is rarely done by smallholder farmers in sub-Saharan Africa but it is important to be aware of crop nutrient needs, especially nitrogen, phosphorus, and potassium, which are commonly deficient in these soils (Margaret et al., 2014; Sinclair and Vadez, 2012; Wortmann et al., 1998a).

Bean is generally considered to be a poor N fixer (Graham and Ranalli, 1997), but inoculation with appropriate *Rhizobium* species can increase grain yields in East Africa (Maingi et al., 2001). High levels of N fixation have been documented when the crop is not limited by other constraints (Giller et al., 1998; Amijee and Giller, 1998; Hardarson et al., 1993), and for that reason it is very important to address low soil P to prevent severely reducing symbiotic nitrogen fixation (SNF) or limiting root expansion (Graham and Ranalli, 1997; Beebe et al., 2014). Adequate K is required for improved tolerance to drought stress, protection against biotic stresses, optimal growth and productivity (Oosterhuis et al., 2014), and as cropping intensifies and higher amounts of K are exported from the field (Mengel and Kirkby, 1980). Potassium is frequently removed in large amounts from fields in sub-Saharan Africa, because crop residues are typically removed from the field at harvest rather than incorporated or left on the soil surface (Giller et al., 2009), further worsening soil K availability (Oosterhuis et al., 2014). The addition of K can increase the competitiveness of bean and therefore may also be important for weed management (Ugen et al., 2002).

Additional constraints to bean production by smallholder farmers include strong negative effects of foliar disease on bean yield in South-Central Uganda. The application of foliar or seed-applied fungicides can decrease the impacts of diseases; however, the development and deployment of bean cultivars with improved host plant resistance to commonly occurring diseases has been one of the most important strategies to improving bean yield (Sinclair and Vadez, 2012). Cultivars that are disease resistant offer a form of protection to farmers who are less likely to be able to afford pesticides and pathogen-free seed (Graham and Ranalli, 1997).

Bekunda (2002) and Esilaba et al. (2005) expressed the need for farmers to reverse soil nutrient depletion through better management of their soils and cropping systems. The development of improved management systems that alleviate the aforementioned constraints is necessary to improve grain yield and profitability. The aim of this study was to compare bean productivity and profitability as influenced by management system and cultivar on Phaeozem soil in south central Uganda.

MATERIALS AND METHODS

Experimental site

The experimental site was located approximately 13 km northeast of Masaka, Central Region, Uganda (latitude 0° 15’ 45.6228” S; longitude 31° 48’ 49.8708” E; altitude 1253 m). The climate is tropical with a bimodal rainfall pattern (Jones et al., 2013). The March-June period, Rainy Season A, averages 465 mm, while the second rainy period, Rainy Season B, averages about 540 mm

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Table 1. Monthly precipitation during the course of the study, long-term precipitation, and long-term temperature. LT is long term (1990-2012) mean for Uganda (World Bank Group, 2015).

Month	Precipitation* (mm)		Precipitation* (number of rainy days)		Mean Precipitation (LT) (mm)	Mean Temperature (LT) (°C)
	2014	2015	2014	2015	1990-2012 avg.	1990-2012 avg.
January	-	3	-	2	42	23.9
February	-	34	-	4	44	24.9
March	-	108	-	8	96	24.5
April	-	364	-	17	152	24.0
May	394	298	18	15	129	23.2
June	103	50	7	4	88	22.7
July	77	-	7	-	83	22.3
August	106	-	6	-	114	22.7
September	97	-	8	-	118	22.9
October	112	-	8	-	142	23.1
November	69	-	9	-	111	23.5
December	63	-	11	-	56	23.5
March-June	-	820	-	44	465	23.6
August-December	447	-	42	-	541	23.1
January - December	-	-	-	-	1175	23.4

*Precipitation values recorded within 1 km of the experimental site, located 13 km NE of Masaka, Central Region, Uganda.

from August-December (Table 1). The soil at the location is called Liddugavu (black) in the local language, but is defined as a Phaeozem using the FAO-UNESCO soil legend and as a Hapludoll using USDA Soil Taxonomy (FAO, 1988; USDA NRCS, 1999). The soil at the experimental site was a sandy clay loam texture and formed from alluvial deposits. Prior to adding soil amendments, soil at the 0 to 15 cm depth had a pH range of 6.6 to 6.8, Mehlich3-P ranged from 20 to 30 mg kg^{-1}, and organic matter ranged from 36 to 37 g kg^{-1}. Long term mean annual precipitation in Uganda is 1175 mm, with about 86% occurring during the two crop growing seasons (World Bank Group, 2015). Precipitation data for the specific research site were not available before this project. According to the landowner, prior to the initiation of this study, the site had been in a maize (*Zea mays* L.), bean, groundnut (*Arachis hypogaea* L.), banana (*Musa* × *paradisiaca* L.), and cassava (*Manihot esculenta* Crantz) intercrop.

Experimental design

The study was initiated in July 2014 and continued over two seasons, the second rainy season of 2014 (2014B), from the end of August through the beginning of December, and the first rainy season of 2015 (2015A), from the end of March through the middle of June. The experimental design was a randomized incomplete block in a split-plot arrangement. Management system was the whole-plot factor and included the Conventional Farmer System (CFS), Improved Farmer System (IFS), and High Input System (HIS) (Table 2). The subplots were four bush type common bean cultivars. Two cultivars, NABE 14 and NABE 15, were new and improved, and the other two, K132 and NABE 4, were conventional cultivars. The new cultivars were released 7 to 16 years later (2006 and 2010) than the older cultivars (1994 and 1999) and have greater resistance to several bean diseases prevalent in the south-central region of Uganda. Individual subplot size measured 6 × 4 m. There were four replications of each management system × cultivar subplot combination, except for three subplots, which were excluded due to limited land availability. Replications were blocked perpendicular to the slope.

Crop management practices

Perennial crops and residual weeds from the previous rainy season were removed using a hand hoe more than one month prior to planting in the 2014B season. Ground agricultural limestone with 68.85% effective calcium carbonate equivalent (ECCE) containing 38% Ca, 0.29% Mg, 0.10% S, and 1.24% P was applied at 295 kg ha^{-1} to supply Ca at 112 kg ha^{-1}. Potassium was not applied in the 2014B season, because results from preliminary soil tests in January 2014 showed adequate levels (Liebenberg, 2002). Post-harvest soil results showed available K was as low as 74 mg kg^{-1} in some plots, therefore muriate of potash was broadcast by hand prior to tillage in the 2015A season at 112 kg K_2O ha^{-1} in the IFS and HIS. One to two weeks prior to planting, tillage was conducted with a hand hoe to a depth of 15 to 20 cm. Beans planted in CFS were scatter planted at a density of 10 seeds m^{-2}, while beans in IFS and HIS were planted in rows 50 cm wide with seeds planted every 10 cm, which resulted in the recommended planting density of 20 seeds m^{-2} for both the IFS and HIS (Uganda Export Promotion Board, 2005). The 10 seeds m^{-2} rate for the CFS was determined by extensive sampling of farmer bean fields in Masaka district, the previous rainy season (unpublished results).

Bean seeds were obtained from Community Enterprises Development Organization (CEDO, Rakai, Uganda). Seed for HIS were treated with VITAVAX® (Bayer CropScience, Research

Table 2. Agricultural inputs and management methods for each management system in the 2014B season and the 2015A season. 2014B is 2014 second rainy season, 2015A is 2015 first rainy season, CFS is Conventional Farmer System, IFS is Improved Farmer System, HIS is High Input System.

Property	Units	2014B			2015A		
		CFS	IFS	HIS	CFS	IFS	HIS
Lime	kg ha^{-1}	0	295	295	0	0	0
P_20_5	kg ha^{-1}	0	34	34	0	45	45
K_2O	kg ha^{-1}	0	0	0	0	112	112
Vitavax	applied	No	No	Yes	No	No	Yes
Rhizobia	applied	No	No	Yes	No	No	Yes
Planting	seeds m^{-2}	10	20	20	10	20	20
Planting	method	Scattered	Rows	Rows	Scattered	Rows	Rows
Fungicide	g ha^{-1}	0	0	458	0	0	458
Insecticide	L ha^{-1}	0	0	2.5	0	0	2.5
Weeding*	frequency	Twice	Twice	Weekly	Twice	Twice	Weekly

*Weeding was done by hand between plants and with a hand hoe between rows.

Triangle Park, NC) fungicide (carboxin). Seeds planted in HIS were inoculated with Mak-Bio-Fixer rhizobia obtained from Makerere University prior to planting. Before planting, triple superphosphate (0-46-0) was banded at 33.6 kg P_2O_5 ha^{-1} in IFS and HIS in the 2014B season and at 44.8 kg P_2O_5 ha^{-1} in these systems in the 2015A season. Bands were placed in hand dug furrows at a depth of 8 to 10 cm and covered with 2 to 4 cm of soil, similar to the technique described by Lunze et al. (2012). Beans were then placed at the recommended depth of 3 to 5 cm (Liebenberg, 2002; Amongi et al., 2014) before being covered with soil using a hand hoe. Beans were planted on 19 and 20 August during the 2014B season and 24 and 25 March during the 2015A season.

Formulated azoxystrobin was applied as a foliar fungicide at 458 g ha^{-1} to HIS during both seasons. The fungicide was applied using a hand-pumped backpack sprayer in approximately 625 L H_2O ha^{-1} at the early stages of R8 pod filling in the 2014B season and at the late stages of R7 pod formation in the 2015A season. Four days after applying the fungicide in the 2014B season, the insecticide cypermethrin was foliar-applied to HIS beans at 2.5 L ha^{-1} with the same hand-pumped backpack sprayer in approximately 625 L H_2O ha^{-1}. Control of aphids was not needed in the 2015A season, therefore cypermethrin was not applied.

Weeding was done by hand between plants and with a hand hoe between rows twice per season for CFS and IFS. The first weeding was done at V3 in the 2014B season and between V3 and V4 in the 2015A season. The second weeding occurred between R7 and R8 both seasons. Weeding was done weekly for HIS, using the same method, so that weeds were never competitive with beans.

Crop and soil data collection

Pre-amendment and post-harvest soil samples were collected at a depth of 0 to 15 cm from 12 subsamples collected from each replication of each whole-plot. Soil samples were analyzed for pH and electrical conductivity (EC) using the potentiometric method. Extractable Al (1-N KCl), organic matter (Walkley-Black C/0.58), and N (Kjeldahl) concentrations were determined by colorimetry. The cation exchange capacity (CEC) was calculated according to Brady and Weil (2007). After extraction with Mehlich-3, inductively coupled plasma optical emission spectrometry (ICP-OES) was used for soil sample analysis of P, K, Mg, Ca, Na, Al, Mn, S, Cu, B, Zn, and Fe following extraction with Mehlich-3.

Phenological development stages were recorded weekly in each plot using the standard system developed for common bean (Van Schoonhoven and Pastor-Corrales, 1987). Briefly, V1 is emergence, V3 is first trifoliate leaf, V4 is third trifoliate leaf, R5 is preflowering, R6 is flowering, R7 is pod formation, R8 is pod filling, and R9 is physiological maturity. Between R8 and R9, aboveground crop biomass was determined by hand clipping five bean plants per plot. Biomass samples were oven-dried at 60°C for 7 days and then weighed. Yield, yield components, and extended plant height data were collected from all bean plants within the area harvested from each plot. The area harvested in CFS was selected by randomly placing two 1.0 m^2 quadrats in each plot (2.0 m^2 total). The IFS and HIS yield samples were determined from 2.0 m^2 in each plot. Stand density of bean at R9 stage was determined at harvest by counting the number of plants within each harvested area. Extended plant height was measured on every plant harvested, up to a maximum of ten plants per subplot. At harvest, all pods were hand-picked, counted, placed in a paper bag, and weighed. Pods were placed in an oven at 60°C until dry. Grain was shelled from pods by hand, counted, and weighed. The pod harvest index (PHI; dry weight of seed at harvest/dry weight of pod at harvest × 100), pod number per area (pods m^{-2}), and seed number per pod (seeds pod^{-1}) were computed as described by Beebe et al. (2013). Grain yields are reported at 100% dry matter.

Soil volumetric water content (VWC) was determined using a calibrated FIELDSCOUT® TDR 300 Soil Moisture Meter (Spectrum Technologies, Inc., Plainfield, IL). Sampling occurred weekly in each subplot at two points for each of the two depths, 7.5 and 20 cm.

The costs of production and market prices of beans were determined using local market prices for all agricultural inputs, except rhizobia, which was unavailable in the local market. Rhizobia inoculant was available at Makerere University; it was assumed that inoculation will occur every four seasons. The economic return to labor and management (ERLM) was based on land rental costs collected from farmers in the Masaka district. The market price of bean used in the analysis assumed beans were sold immediately after harvest when farm gate prices ranged from 1500 to 1700 UGX kg^{-1}, depending on the cultivar. The UGX to USD conversion rate used for this study was 3400 UGX = 1 USD.

Statistical analysis

Data were analyzed as a randomized incomplete block in a split-plot arrangement with management system as the whole-plot factor and bean cultivar as the subplot factor. Statistical analyses for yield, yield components, height, biomass, PHI, VWC, phenological, and economic data were performed with the GLIMMIX Procedure of SAS V9.4 (SAS Institute, 2013). Least squares means were generated for all variables when significant F values ($P < 0.05$) were observed and then separated using the LINES option at P = 0.05. Soil data were analyzed using PROC GLM, which enabled us to separate means using the multiple mean comparison of the protected least significant difference. Differences among treatments were reported as significant at P = 0.05 except for the phenological differences between treatments, which were reported as significant at P = 0.01. Management system, cultivar, rainy season, and weeks after planting (WAP) were treated as fixed effects. Replication, replication × management system, and cultivar × replication × management system were considered random effects.

RESULTS

Climate

Long-term mean annual precipitation for this region is 1175 mm, 86% of which occurs during the crop growing season (Table 1) (World Bank Group, 2015). Total precipitation during our study, July 2014 through June 2015, was 1381 mm, 18% greater than the long-term mean. Precipitation during the dry season months, July and again January through February, amounted to only 67% of the 22-year average for these months. However, the precipitation in April 2015 was 139% greater than that of the long-term average and the precipitation in May 2015 was 131% greater than that of the long-term average.

Soil

The pre-amendment soil results did not show differences among management systems; however, there were greater levels of extractable Al, Cu, Fe, N, and Mn in the post-harvest soil compared to the pre-amendment soil (Table 3). Additionally, management systems differed for post-harvest soil copper concentration. The IFS had 7 and 10% more copper than HIS and CFS, respectively. The available P, K, and Ca were similar between management systems across both sampling dates despite receiving different amounts of each as soil amendments.

Volumetric water content

The VWC differed for rainy season and the interaction of rainy season × depth. All other main effects and interactions were not significant. There was an interaction of rainy season × depth for VWC over two seasons. VWC differed for depth in both seasons. Mean VWC in the 2014B season was 0.20 and 0.23 cm^3 cm^{-3} for 7.5 and 20 cm depth, respectively, while mean VWC in the 2015A season was 0.30 and 0.27 cm^3 cm^{-3} for 7.5 and 20 cm depth, respectively. The 2014B season was wetter at 20 cm depth compared to 7.5 cm depth, while the reverse was true for the 2015A season.

Bean development

Phenological development of beans varied for cultivar, rainy season, weeks after planting (WAP), and the interaction of cultivar × rainy season, cultivar × WAP, rainy season × WAP, and cultivar × rainy season × WAP (Figure 1). In the 2014B season, there was a trend for faster development of NABE 15, while the other cultivars developed more slowly, but at a similar rate to each other, and reaching maturity in 13 weeks. In the 2015A season, development rates were similar for the four cultivars, although maturity was reached in only 11 weeks (Figure 1).

Yield, yield components, height, biomass, and pod harvest index (PHI)

At maturity (R9 stage), stand density of beans differed for management system, cultivar, and the interaction of cultivar × rainy season (Table 4). NABE 14 was among the greatest for stand density both seasons while NABE 15 had the lowest density in both rainy seasons (Table 5).

Height of beans at harvest varied for cultivar, rainy season, and the interactions of management system × rainy season and cultivar × rainy season (Table 4). In the 2014B season, beans had similar height under all management systems (Table 6). Conversely, beans in the 2015A season under HIS were taller than beans under CFS; height of beans in IFS was intermediate and not different from either the CFS or HIS. The NABE 14 and K132 were the tallest cultivars in the 2014B season and the 2015A season; NABE 15 was the shortest entry for both rainy seasons (Table 5).

Pod density of beans differed for management system, cultivar, rainy season, and the interactions of management system × rainy season, cultivar × rainy season, and management system × cultivar × rainy

Table 3. Pre-amendment and post-harvest soil (0 to 15-cm depth) nutrient concentrations, CEC, EC, organic matter, and base saturation results from the three common bean management systems. Soil collected from Masaka District, Uganda with collection period for Pre-amendment in July 2014 and post-harvest in December 2014. CFS is Conventional Farmer System, IFS is Improved Farmer System, HIS is High Input System.

Property	Units	Pre-amendment			Post-harvest		
		CFS	IFS	HIS	CFS	IFS	HIS
pH		6.7	6.6	6.8	6.6	6.5	6.5
CEC	meq $100g^{-1}$	13	14	14	15	16	15
EC(S)	µS cm^{-1}	77	86	84	99	100	111
Extr. Al	meq $100g^{-1}$	0.014^{b}	0.013^{b}	0.015^{b}	0.125^{a}	0.125^{a}	0.125^{a}
P	mg kg^{-1}	20	29	30	27	32	27
K	mg kg^{-1}	74	126	101	89	124	101
Mg	mg kg^{-1}	333^{ab}	311^{b}	360^{ab}	392^{a}	348^{ab}	350^{ab}
Ca	mg kg^{-1}	1710	1828	1850	1898	2058	1910
Na	mg kg^{-1}	40^{a}	55^{a}	51^{a}	11^{b}	45^{a}	27^{ab}
Al	mg kg^{-1}	830	846	854	-	-	-
Mn	mg kg^{-1}	340^{b}	335^{b}	354^{b}	467^{a}	460^{a}	473^{a}
S	mg kg^{-1}	3	3	2	2	3	5
Cu	mg kg^{-1}	2.9c	3.0 c	3.0c	4.0^{b}	4.4^{a}	4.1^{b}
B	mg kg^{-1}	0.5	0.5	0.5	0.7	0.9	0.7
Zn	mg kg^{-1}	5.1	5.7	5.2	6.4	6.6	6.2
Fe	mg kg^{-1}	97^{b}	97^{b}	97^{b}	132^{a}	135^{a}	134^{a}
N	%	0.11^{b}	0.12^{b}	0.12^{b}	0.16^{a}	0.16^{a}	0.16^{a}
OM	g kg^{-1}	36	37	36	38	34	36
C:N	ratio	18	18	18	14	12	13
Base Saturation	%	90	90	92	89	88	88

Means within property followed by the same letter, or no letter, are not different at *P*=0.05. OM as Walkley-Black C/0.58; other elements determined with ICP-OES following extraction with Mehlich-3. Extraction of exchangeable Al done with 1N KCl.

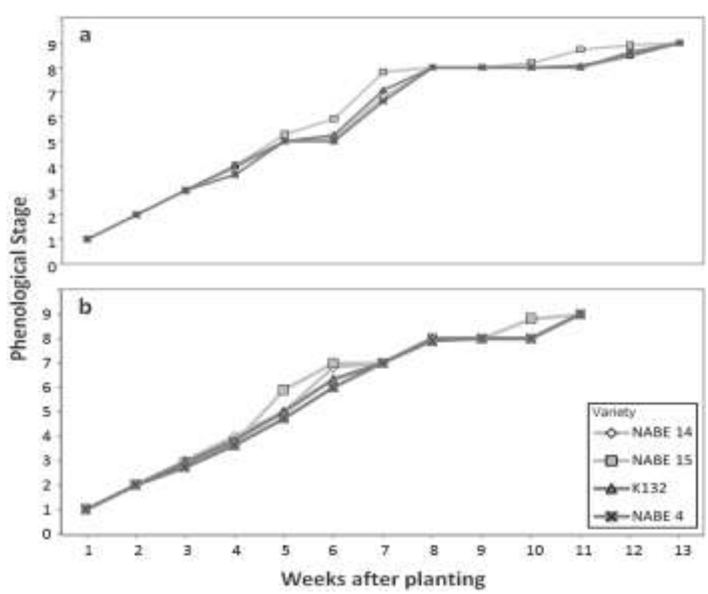

Figure 1. Weekly mean phenological stage of bean for four cultivars in (a) the 2014 Rainy Season B and (b) the 2015 Rainy Season A across three management systems, Masaka, Uganda.

Table 4. Yield, yield components, height, biomass, pod harvest index (PHI), and net profit/loss for four bean cultivars in three management systems for two rainy seasons, Masaka, Uganda.

Treatment	Plant stand (#m^{-2}) R9	Extended plant height (cm)	Pods (#m^{-2})	Seed (#pod^{-1})	Seed size (100 seed weight, g)	Biomass (g plant^{-1}) R8-R9	Grain (kg ha^{-1})	Pod harvest index (PHI)	Economic return to labor and management (USD)
Management system									
CFS	6^{b}	29	40^{b}	2.9	42.5	21	593^{b}	76	212
IFS	14^{a}	31	67^{ab}	2.8	38.7	16	818^{b}	77	124
HIS	16^{a}	34	92^{a}	2.9	43.7	18	1275^{a}	75	297
Cultivar									
NABE 14	14^{a}	36^{a}	90^{a}	3.2	41.7^{ab}	22^{a}	1212^{a}	73^{b}	378^{a}
NABE 15	10c	23c	52^{b}	2.6	37.8^{b}	18^{ab}	668c	81^{a}	79c
K132	11^{b}	34^{ab}	62^{b}	2.8	43.1^{a}	17^{b}	803^{b}c	74^{ab}	165^{b}c
NABE 4	13^{a}	32^{b}	63^{b}	2.9	43.9^{a}	16^{b}	899^{b}	76^{a}	220^{b}
Rainy season									
2014B	12	38^{a}	91^{a}	3.3	44.5^{a}	27^{a}	1318^{a}	76	466^{a}
2015A	12	25^{b}	42^{b}	2.5	38.8^{b}	9^{b}	473^{b}	76	-44^{b}
Significance	-	-	-	*P* > F	-	-	-	-	-
System (S)	***	NS	*	NS	NS	NS	*	NS	NS
Cultivar (C)	***	***	***	***	*	*	***	*	***
S × C	NS	NS	NS	NS	NS	NS	NS	NS	NS
Rainy season (R)	NS	***	***	***	***	***	***	NS	***
S × R	NS	**	*	NS	NS	**	**	NS	***
C × R	**	**	***	***	NS	***	***	NS	***
S × C × R	NS	NS	*	NS	NS	NS	*	NS	*

Means within treatment and column followed by the same letter, or no letter, are not different at P=0.05.*, **, ***, and NS indicate statistical significance at $P \leq$ 0.05, 0.01, 0.001, and not significant, respectively. CFS is Conventional Farmer System, IFS is Improved Farmer System, HIS is High Input System. 2014B is 2014 second rainy season, 2015A is 2015 first rainy season.

season (Table 4). In the 2014B season, pod density increased with increasing input level (Figure 2). In the 2015A season, this same trend occurred with NABE 14 and K132. Conversely, in the 2015A season, pod density of NABE 15 and NABE 4 did not increase with increasing input levels. The interaction of management system × cultivar was not significant in the 2014B season though this interaction was significant in the 2015A season. Cultivars did not differ for pod density within management systems in the 2014B season. Conversely, in the 2015A season, cultivars differed among management systems for pod density. NABE 14 produced more pods m^{-2} than all other cultivars within each management

Table 5. Interaction of cultivar × rainy season for plant stand density, height, seed number, and aboveground biomass of bean at maturity (R9) for two seasons. 2014B is 2014 second rainy season, 2015A is 2015 first rainy season.

Parameter	2014B	2015A
Plant stand ($\#m^{-2}$) R9		
NABE 14	13^{a}	14^{a}
NABE 15	10^{b}	10^{c}
K132	12^{a}	10^{c}
NABE 4	13^{a}	13^{b}
Height (cm)		
NABE 14	39^{a}	34^{a}
NABE 15	32^{b}	15^{c}
K132	38^{a}	29^{a}
NABE 4	41^{a}	23^{b}
Seed ($\#pod^{-1}$)		
NABE 14	3.3^{ab}	3.1^{a}
NABE 15	3.3^{ab}	1.9^{c}
K132	3.0^{b}	2.6
NABE 4	3.5^{a}	2.3^{b}
Biomass (g $plant^{-1}$) R8-R9		
NABE 14	26	18^{a}
NABE 15	30	5^{b}
K132	26	8^{b}
NABE 4	27	6^{b}

Means within measured variable and rainy season followed by the same letter, or no letter, are not different at *P*=0.05.

Table 6. Interaction of management system × rainy season for height and biomass of bean for two seasons. CFS is Conventional Farmer System, IFS is Improved Farmer System, HIS is High Input System. 2014B is 2014 Rainy Season B, 2015A is 2015 is Rainy Season B.

Parameter	2014B	2015A
Height (cm)		
CFS	37	22^{b}
IFS	39	23^{ab}
HIS	37	30^{a}
Biomass (g $plant^{-1}$) R8-R9		
CFS	32^{a}	9
IFS	25^{b}	7
HIS	24^{b}	11

Means within parameter and rainy season followed by the same letter, or no letter, are not different at *P*=0.05.

system in the 2015A season while NABE 15 had the least or was among the least for pod density within each management system.

Seed number pod^{-1} varied for cultivar, rainy season,

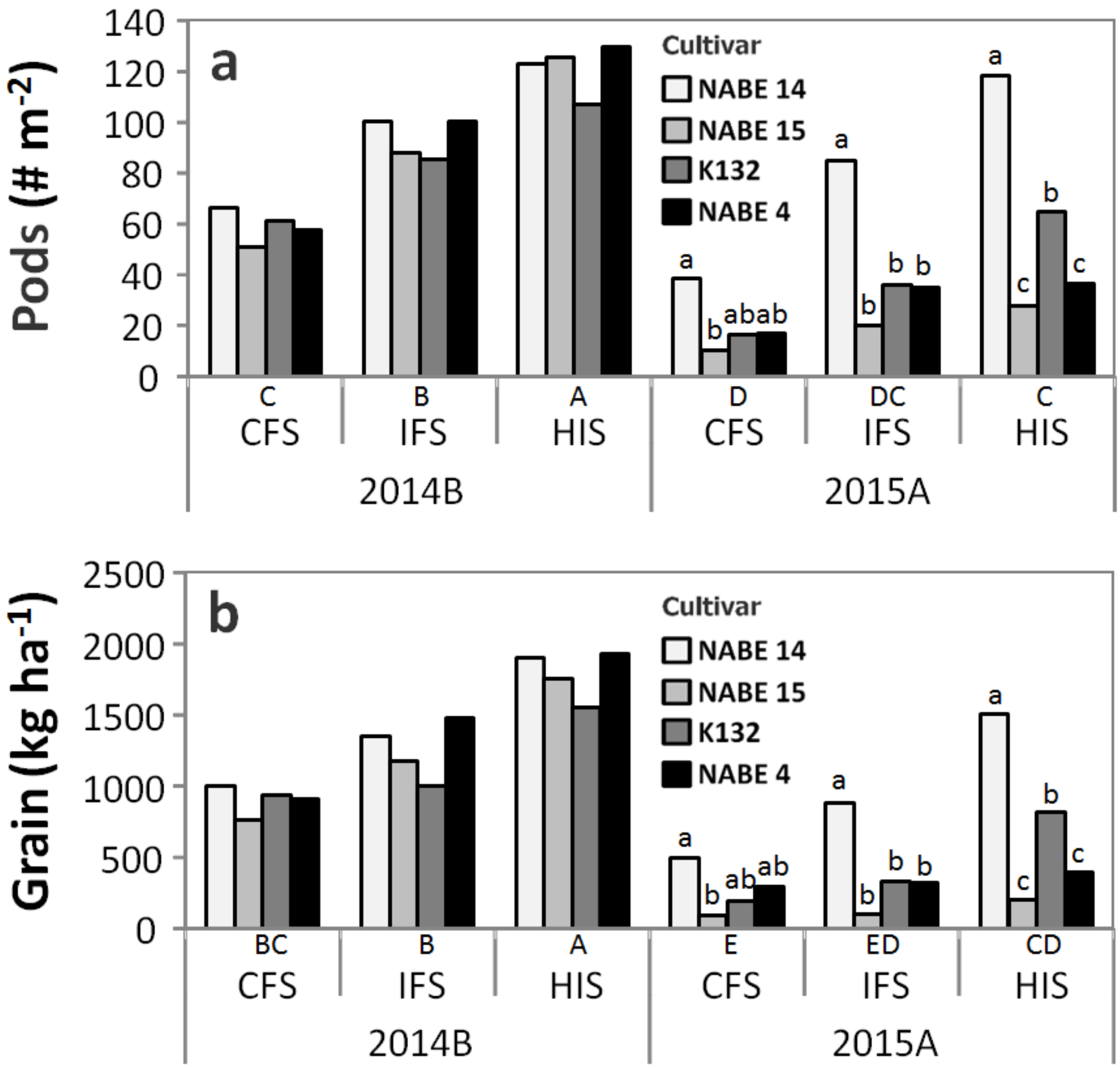

Figure 2. Interaction of management system × cultivar × rainy season for (a) pod density and (b) grain yield of beans. Management systems include the Conventional Farmer System (CFS), Improved Farmer System (IFS), and High Input System (HIS). 2014B is 2014 Rainy Season B, 2015A is 2015 Rainy Season A. Cultivar means within system and rainy season followed by the same lowercase letter, or no letter, are not different at *P*=0.05. System × rainy season combinations followed by the same uppercase letter are not different at *P*=0.05.

and the interaction of cultivar × rainy season (Table 4). Seed number pod^{-1} varied for cultivar both rainy seasons (Table 5). NABE 14 produced more seeds pod^{-1} than the other cultivars while NABE 15 generally produced fewer seeds pod^{-1} than the other cultivars. The 100-seed weight varied for cultivar and rainy season, however, all interactions were non-significant (Table 4). Management system did not influence 100-seed weight. However, seed weight across management systems in the 2014B season was 15% greater than for the 2015A season. K132 and NABE 4 produced the heaviest seeds, weighing 14 and 16% greater than NABE 15, respectively.

Aboveground biomass (g plant^{-1}) varied for cultivar, rainy season, and the interactions of management system × rainy season and cultivar × rainy season (Table 4). In the 2014B season, beans in CFS accumulated 28 and 33% greater biomass than beans under IFS and HIS, respectively; differences were not significant among management systems for biomass in the 2015A season (Table 6). The interaction of cultivar × rainy season was not significant in the 2014B season; however, this

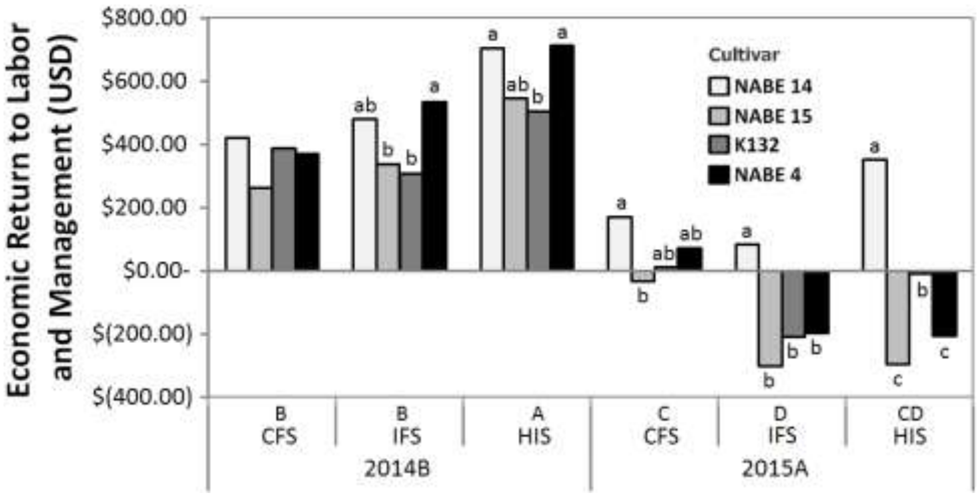

Figure 3. Interaction of management system × cultivar × rainy season for return to labor and management of beans. Management systems include the Conventional Farmer System (CFS), Improved Farmer System (IFS), and High Input System (HIS). 2014B is 2014 Rainy Season B, 2015A is 2015 Rainy Season B. Cultivar means within system and rainy season followed by the same lowercase letter, or no letter, are not different at *P*=0.05. System × rainy season combinations followed by the same uppercase letter are not different at *P*=0.05.

interaction was significant in the 2015A season (Table 5). In the 2015A season, NABE 14 accumulated 260, 125, and 200% greater biomass than NABE 15, K132, and NABE 4, respectively.

Grain yield differed for management system, cultivar, rainy season, and the interactions of management system × rainy season, cultivar × rainy season, and management system × cultivar × rainy season (Table 4). In the 2014B season, grain yield increased with increasing input level (Figure 2). In the 2015A season, this same trend occurred with NABE 14 and K132. However, for this rainy season, grain yield of NABE 15 and NABE 4 did not increase with increasing input levels. In the 2014B season, yields were similar among cultivars within each of the three management systems. In the 2015A season, NABE 14 produced greater yields than the other three cultivars within IFS and HIS, while NABE 4 and NABE 15 produced among the lowest grain yields in these management systems. NABE 14 produced 444% greater yield than NABE 15 under CFS in the 2015A season. The PHI varied for cultivar but no other treatment factor or interaction was significant (Table 4). The PHI for NABE 15 was 11% greater than for NABE 14, but was not different from the other two cultivars.

Economic analysis

Cultivar, rainy season, and the interactions of management system × rainy season, cultivar × rainy season, and management system × cultivar × rainy season influenced economic return to labor and management (ERLM) (Table 4). However, management system and the interaction of management system × cultivar did not influence the ERLM. In the 2014B season, net profit was the greatest for HIS (Figure 3). In the 2015A season, CFS realized greater profits than IFS, while HIS was intermediate and did not differ from CFS or IFS. In the 2014B season, net profits were similar among cultivars within CFS, but differed for IFS and HIS. Of the four cultivars tested in the HIS in the 2014B season, NABE 14, NABE 15, and NABE 4 realized greater profits than K132. Over both seasons, NABE 14 remained profitable in all six management system × cultivar × rainy season combinations and showed greater positive returns than other cultivars. In the 2015A season, NABE 15 realized the highest net loss in each management system; NABE 14 produced \$200, \$406, and \$678 ha^{-1} greater profits than NABE 15 within CFS, IFS, and HIS, respectively. About 58, 88, and 90% of the total cost of production were from agricultural inputs in CFS, IFS, and HIS, respectively (results not presented).

DISCUSSION

Climate, volumetric water content, and bean development

Precipitation during the 2014B season was normal and all other environmental conditions were suitable for good growth of beans; however, precipitation during the 2015A season was abnormally intense and frequent, resulting in unusually long periods of high VWC in the early part of the growing season. The increase in soil VWC may have led to the greater frequency of diseases (results not presented) and damping-off (Athanase et al., 2013) in the 2015A season, which appeared to be related to the reduction in R9 plant stands and overall lower grain yield compared to the 2014B season (Figure 2). It was also believed that the VWC would increase with increased management level, because IFS and HIS had greater planting density, which enabled them to canopy quicker and therefore prevent soil water loss through evaporation; however, significant differences were not observed. The differences in phenological development between cultivars at each date were likely due to the differences in maturity groups between the four cultivars. NABE 15 was a short maturity cultivar, while K132 was an intermediate, and NABE 14 and NABE 4 were long maturity cultivars.

Management and cultivar selection

Farmers prefer to plant common bean on Phaeozem soil (Liddugavu in the local language) if it is available because they recognize that this soil is generally more fertile than other soils, providing a better growing environment for beans. Because the Liddugavu soil type is considered fertile, these soils typically receive little or no fertilizer applications for bean production under current management systems used by farmers. As a result, bean yield on this soil is still much lower than its potential.

Beans were planted at an increased density to promote faster canopy closure which decreases soil water evaporative losses, shades out weeds, and captures more light. We replanted beans on the same plots in the second season to develop a better understanding of nutrient carry-over effects. Doing this also allowed us to determine yield response of improved management systems in a bean-bean rotation which many smallholder farmers are now practicing due to limited land resources (Ampofo et al., 2001).

Bush-type bean cultivars were employed in this study because these cultivars are the most prevalent type in the region. Three of the four cultivars (K132, NABE 4, and NABE 15) in this study were the most popular cultivars grown in Uganda. NABE 14 was included in this study because it was a newer cultivar with tolerance to low soil fertility and resistance to angular leaf spot (*Phaeoisariopsis griseola*) (ALS), bean common mosaic virus (*Potyvirus* spp.) (BCMV), and root rots (*Fusarium solani* f. sp. *phaseoli*). Therefore, this cultivar should have better yield potential under greater disease pressure. The beneficial effects of host plant resistance to foliar and root diseases in NABE 14 were apparent in the abnormally wet 2015A season. To our surprise, NABE 15 grain yields were very poor for a newly released cultivar, especially during the 2015A season. Not all new and improved cultivars perform well under every environment and we suggest that multiple cultivars be included in subsequent cropping systems studies. NABE 15 and the older cultivars, K132 and NABE 4, likely produced lower yields than NABE 14 because they are susceptible to root rot, which was observed in the wet 2015 Rainy season A.

Agricultural inputs and soil nutrient status

Potassium fertilizer was not applied in the 2014B season, because preliminary soil data showed extractable K was adequate for bean production. However, mid-season, pre-amendment soil nutrient results became available that documented soil was deficient in both P and K. Determining fertilizer application was challenging, because very little work has been done on fertilizer recommendations for common bean in Uganda, especially for individual soil types within different regions of the country (Benson et al., 2013). Additional studies should develop recommendations for fertilizer application rates based on test values within each region of Uganda, because current recommendations broadly recommend fertilizer rates for entire regions or soil types irrespective of management history or actual nutrient status.

Nitrogen can be supplied to beans by N fixation following inoculation of seeds with appropriate *Rhizobium* spp., offering a cost effective alternative to N fertilizers (Hardarson and Atkins, 2003) or soil mining. Even with good N fixation, several reports suggest that beans may be nitrogen limited without supplemental nitrogen application (Liebenberg, 2002; Wortmann et al., 1998b). We inoculated seeds prior to planting in HIS and did not apply nitrogen, because beans can fix nitrogen at rates greater than 100 kg ha^{-1} under optimum conditions (Graham and Ranalli, 1997; Hardarson and Atkins, 2003). Optimum conditions generally occur under P fertilization and liming, which is appropriate to ameliorate low pH or Ca deficiency (Giller et al., 1998; Lunze et al., 2012; Wortmann et al., 1998b). Management practices and inputs were done to optimize conditions for N fixation in HIS by applying lime (38% Ca) and P fertilizer. Nitrogen deficiency was only noted in one HIS plot, suggesting nitrogen needs were not limiting following rhizobia inoculation. Even though both improved management systems received P and lime applications, the post-harvest soil results unexpectedly showed no differences in P or Ca concentrations compared to the pre-amendment soil results. This could be attributed to increased plant uptake or P being complexed by reactions in soil (Fungo et al., 2011).

Pests and diseases

Lower yields across management systems, cultivars, and the management system × cultivar interaction were expected in the 2015A season, because our study was conducted on the same plots as the previous season. Disease prevalence was greater in the 2015A season which may have been due to the bean-bean rotation or the greater amounts of rain and increased number of rainy days compared to the 2014B season (Athanase et al., 2013). Increased frequency and amount of rain in the 2015A season may have also been the cause for the decreased presence of aphids (Weisser et al., 1997). Crop rotation can be an effective management practice to decrease disease pressure.

Economic analysis

Although the Economic Return to Land and Management (ERLM) results in this study did not consistently show an increase in net profits by increasing input levels, improved yields document there is great potential for increased profits with improved management systems if input costs decrease and/or grain prices increase. Uganda currently imports many of its agricultural inputs such as synthetic fertilizers, lime, herbicides, and other pesticides resulting in increased costs.

Improved management systems were more labor intensive due to the labor required for applying inputs, and if labor was hired it would represent approximately 50% of the total cost of production in this study. However, there is great variability in labor costs due to the inconsistency of prices between villages, field locations, presence or absence of weeds, relationship with farmers, and seasonal demand. The ERLM does not include the cost of labor in the economic analysis because most labor on smallholder farms in this region of Uganda is provided by members of the family. Furthermore, the opportunity cost for these family members is very low because there are very few opportunities for off-farm employment. Therefore, the ERLM was included in the economic analysis instead of the economic return to management.

A significant portion of the total production costs were from imported and expensive agricultural inputs, especially agricultural lime. With recent bean values, production costs, and production levels it may not always be profitable at this time for smallholder farmers to invest in expensive agricultural inputs such as mineral fertilizers to replenish or maintain soil nutrient reserves or alleviate soil infertility (Nabhan et al., 1999). This is especially important in a region experiencing extensive changes in rainfall patterns in recent years, because these management systems may not recover the value of fertilizer or other inputs (Ojiem et al., 2014).

Regarding cultivar selection, the improved cultivar NABE 14 had the potential for greater returns than other bean cultivars due to its ability to produce higher yields under varying levels of fertility, moisture stress, and pest and disease pressure. Similar to our analysis for profitability, Broughton et al. (2003) compared newly released and older bean cultivars and reported profits increased 300 % or more with the use of improved cultivars in Central and South America. We hypothesized that improved bean cultivars could increase grain yields, especially under greater input levels and management practices. Our production results support conclusions from the Uganda Export Promotion Board (UEPB) (2005), which stated that higher input systems provided greater yields than subsistence bean management systems and low input systems. However, our ERLM results differ from those of the UEPB because we did not consistently show a greater return on investment as input and management levels increased, particularly for bean cultivars with low levels of resistance to diseases.

Conclusions

Increasing management level and planting bean cultivars resistant to common bean diseases improved grain yield in both rainy seasons. The increase in yield was due to in the combination of planting arrangement and density, fertilizer application, and improved N fixation and weed and pest management. All inputs were obtained locally, except the rhizobia inoculant, suggesting that increased yields and profitability are obtainable by farmers, especially when utilizing NABE 14 under HIS. Our production results and economic analysis suggest that common bean production systems with increased use of agricultural inputs and improved pest management strategies are acceptable methods for farmers to alleviate constraints limiting bean production and profitability.

Conflict of Interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Sweet potato cultivars grown and harvested at different times in semiarid Brazil

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Sweet potato constitutes a source of energy and nutrient which is very important economically, especially, for the poorest people in the world, supplies calories, vitamins and minerals in the diet. The determination of the harvest age has great influence on vegetative production, quality, productivity and root biomass. The planting season is determined by climatic elements, which have influence on the growth, development and crop productivity. The objective of this paper was to evaluate the agronomic performance of sweet potato cultivars, as a function of the age of harvest in two growing seasons. Two experiments were conducted, the first in the rainy season and the second in the dry season in semiarid Brazil. In both experiments, the experimental design was a randomized block with split plots with four replications, being the plot formed by three cultivars (ESAM 1, Paraná and Mãe de Família), and the subplot by 5 harvest times (90, 105, 120, 135 and 150 days after planting). The length and diameter of commercial roots, dry mass of roots and shoots, and fitomass production were determined. The diameter, total dry mass of roots, commercial and total productivities of roots showed increasing responses with increasing harvest age in both crop growing seasons. The Paraná cultivar showed the best productive performance among cultivars. The harvest age of 150 days after planting was more productive. The best time of cultivation was in the dry season. Considering the importance of sweet potatoes, further studies are recommended in order to solve some problems related to adaptability and cultural reproduction in other regions to elucidate the effects of harvesting ages and growing seasons at longer intervals.

Key words: *Ipomoea batatas*, productivity, roots, tuberous.

INTRODUCTION

The sweet potato is one of the most important foods in the world because of its high yield and nutritional value (Data and Eronico, 1987; Raemaekers, 2001). The United Nations Food and Agriculture Organization (FAO)

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(1990, 2011) reported that sweet potato (*Ipomoea batatas* (L.) Lam.) is a very important crop in the developing world and a traditional culture, but less important in some parts of the developed world. According to FAO (2011), sweet potato is one of the seven crops in the world that produce over 105 million tons of edible products annually. Only potato and cassava, among the roots and tubers produce more. Only China produced 80-85% of sweet potato in the world, while other Asian countries had the highest production, followed by Africa and Latin America (Centro Internacional de la Papa, 2009).

The main producing countries are China, Russia, India, Ukraine and the USA, with annual worldwide production of potatoes in 2009 of about 329,581 million tons (FAO, 2011). Sweet potato [*Ipomoea batatas* (L.) Lam] in Brazil, is considered the fourth most consumed vegetable crop; in 2014, it recorded a production of 525,140 tons in 39.705 ha with an average productivity of 13.2 t ha^{-1} of roots, highlighting the Rio Grande do Sul as the largest producer. In the Northeast, where culture has participation in the economic and social scenarios, the state of Sergipe stands out as the largest producer with an output of 40,271 tons in 2014 and yield of 12.9 t ha^{-1}, followed by Paraíba State with a production of 28,121 tons and yield of 7.56 t ha^{-1} (IBGE, 2015). In addition to the ease of cultivation, the species shows a rich germplasm, in which is found variability for various features, resulting in ample adaptation to different environments, cultivation methods as well as allows meeting different consumer markets, since coloring of the pulp is an important factor for selection of the market (Ritschel and Huaman, 2002).

The sweet potato, beside been a rich source of starch, contains proper amount of secondary metabolites and small molecules that play an important role in various processes (Friedman, 1997).

Sweet potato cultivars with coloring of purple, white and pink films, and cream and white pulps are well accepted in the consumer market. However, film cultivars and orange pulp are not common in the local market, even though they stand out as a source of carotenoids and vitamin C, and can act as antioxidants (Padmaja, 2009). The use of sweet potatoes with orange flesh is seen as a viable alternative to supply the vitamin A deficiency in poor populations, and is a source of low cost and abundant of β-carotene (Rodriguez-Amaya and Kymura, 2004).

The species has continuous tuberset and in general, the harvest season is determined by factors such as demand and market price (Queiroga et al., 2007). Thus, besides cultivars with suitable coloring at the consumer market demand, sweet potato cultivation lacks information to obtain a quality product and economically feasible. Among these informations can mention the growing season (Medeiros et al., 1990; Villordon et al., 2010), the used cultivar and the appropriate age to harvest the roots.

Thus, the determination of the best cultivar and harvest age associated with better growing season can provide guidance to farmers producing sweet potato crop in a particular region, contributing to the increase of the productive chain, making it more efficient and profitable, adapting always to supply the demand. In this sense, the objective of this study was to evaluate the agronomic performance of sweet potato cultivars, as a function of the age of harvest in two growing seasons.

MATERIALS AND METHODS

Two experiments were conducted at the Experimental Garden at Federal Rural University of Semi-Arid (UFERSA), geographically located at 5° 11 'S 37° 20' W and 18 m. The first experiment was carried out from February 10 to 10 July and the second from 29 June to 28 November 2015. The climate can be classified according to Köeppen in BShw as dry and very hot, with two defined seasons: a dry (June to January) and a rainy season (February to May) (Carmo Filho and Oliveira, 1989). The average meteorological data of the period of the experiments are presented in Figure 1.

The soil of the experimental area was classified as Ultisol Eutrophic Abrupt, with sandy texture (Embrapa, 1999), whose chemical analysis, in the depth of 0.20 m, prior to installation of each experiment are shown in Table 1. Two months prior to installation of each experiment, branches of the cultivars were planted with the purpose of multiplication.

The experimental design was a randomized block in split plot with four replications, with the plot formed by the three cultivars (ESAM 1, Paraná and Mãe de Família), and the subplot by the five harvest times (90, 105, 120, 135 and 150 days after planting).

Cultivars showed the following characteristics: ESAM 1, fusiform roots, pink outer skin, cortex and white pulp (Murilo et al., 1990); Paraná, rounded roots and orange pulp (Moreira et al., 2011); Mãe de Família has long roots irregular with cream outer film and white pulp (Albuquerque et al., 2015). Plowing, disking and soil collection were carried out for analysis. Windrows were raised at 30 cm height manually with the aid of a hoe.

The spacing used was 1.0 m between rows (windrows) and 0.30 m between plants. The experimental plots were composed of four lines 3.0 m long, totaling 12.0 m^2 of total area, with a harvest area of 4.8 m^2. In each hole, were planted two branches with six buds each, three buds been buried, totalizing a population of 80 plants per experimental plot.

The fertilization was carried out as recommended for culture (IPA, 2008) and the irrigation was located drip with daily parceled irrigation interval in two applications (morning and afternoon), as water requirement of the crop. Manual weeding was performed whenever needed.

At harvest, the following characteristics were evaluated: length (CRL) and diameter (DCR) of commercial roots in cm (Cavalcante et al., 2010); root dry mass (RDM) and dry mass of shoots (DMS), estimated in four plants in the harvest area of each plot after drying in an oven with forced air, with temperature set at 65°C until constant mass, and expressed in t ha^{-1} (Oliveira, 2013); fitomass production (FP), obtained from the harvest of branches, to 3.0 cm from the ground, of all plants of the harvest area of each plot, and expressed in t ha^{-1} (Cavalcante et al., 2010); commercial productivity of roots (CPR) and total of roots (TPR), obtained from the weighing of 28 plants roots of the harvest area of each plot and expressed in t ha^{-1} (Cavalcante et al., 2010). Roots weighing more than 80 g were considered commercial, and those outside this standard or with defects were classified as non-commercial

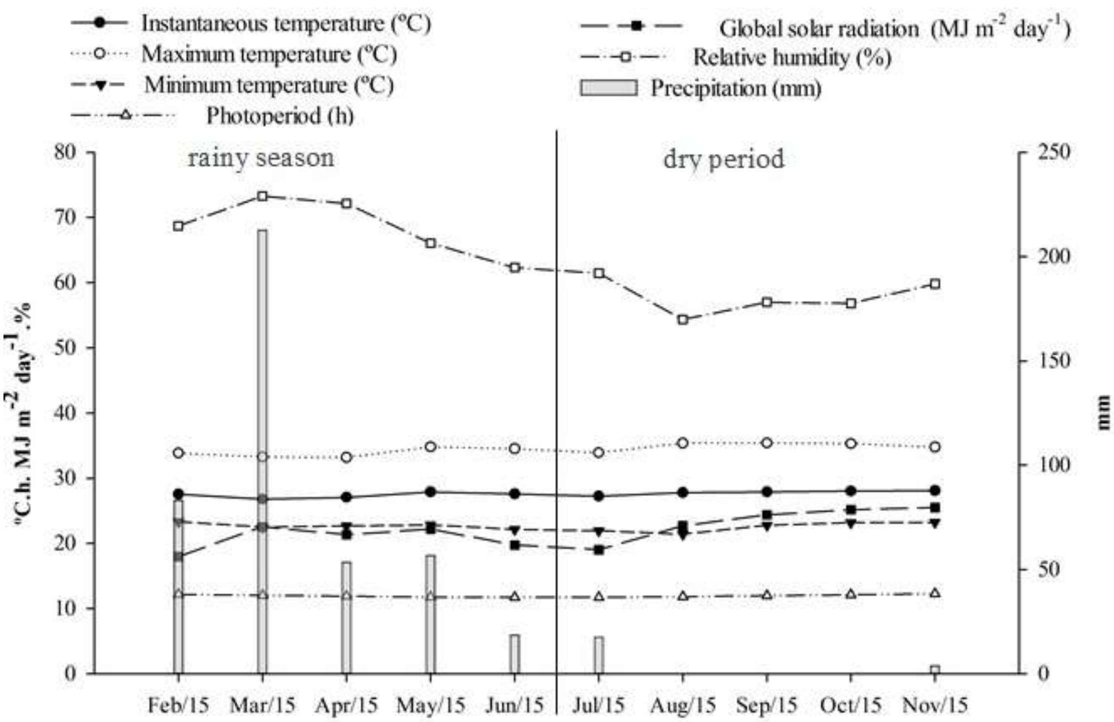

Figure 1. Average values of the instantaneous, maximum and minimum (C) temperatures, photoperiod (h), global solar radiation (MJ m^{-2} day^{-1}), relative humidity (%) and precipitation (mm) in each growing season of the sweet potato.

Table 1. Soil chemical analyzes in each growing season, in the depth of 0.20 m.

Growing seasons	N (g kg^{-1})	OM (g kg^{-1})	K	P	Na	Ca	Mg (dm^3)	pH	EC
			mg dm^3			($cmol_c$)			(dS m^{-1})
I	0.28	11.5	172.6	135.56	15.94	2.89	1.30	8.25	8.25
II	1.54	29.2	62.90	211.5	5.51	6.00	1.85	7.67	7.67

(Embrapa, 1995).

Analysis of variance for the evaluated characteristics was performed through the application SISVAR 3:01 (Ferreira, 2003). When the homogeneity of variance was observed, a joint analysis was applied, considering the growing season as a new factor. In quantitative factors, the fitting procedure of response curve was performed using the program Table Curve 2D (Systat Software, 2002), as prepared in Sigma Plot graphics 12.0 (Systat Software, 2011). The Tukey test ($p<0.05$) was used to compare the averages between growing seasons.

RESULTS AND DISCUSSION

After accepting the homogeneity of variances for length (CRL) and diameter (DCR) of commercial roots, root dry matter (RDM), dry mass of shoot (DMS), fitomass production (FP) a joint analysis of experiments was done, and a triple interaction was observed for all these features. The largest CRL values were recorded in the second growing season. Regardless of the age of harvest and growing season, the cultivar Mãe de família was presented the highest CRL (19.70 cm) to 120 DAP in the second growing season (Figure 2B).

The cultivar ESAM 1 showed an increasing linear correlation with respect to harvesting age in the second growing season for CRL, reaching 15.27 cm at 150 DAP (Figure 2B), indicating that the increase of the field period promoted greater root growth, differing from that of the first growing season, where decrease in the length of commercial roots in the cultivar at 150 DAP (13.49 cm) was observed (Figure 2A).

For the diameter of commercial roots (DRC), the highest values were found in the second growing season, being that the cultivar Paraná was that presenting the highest DRC at the 150 DAP, reaching 6.38 cm in the first growing season (Figure 3A). The results of this study were higher than those of Queiroga et al. (2007), in which

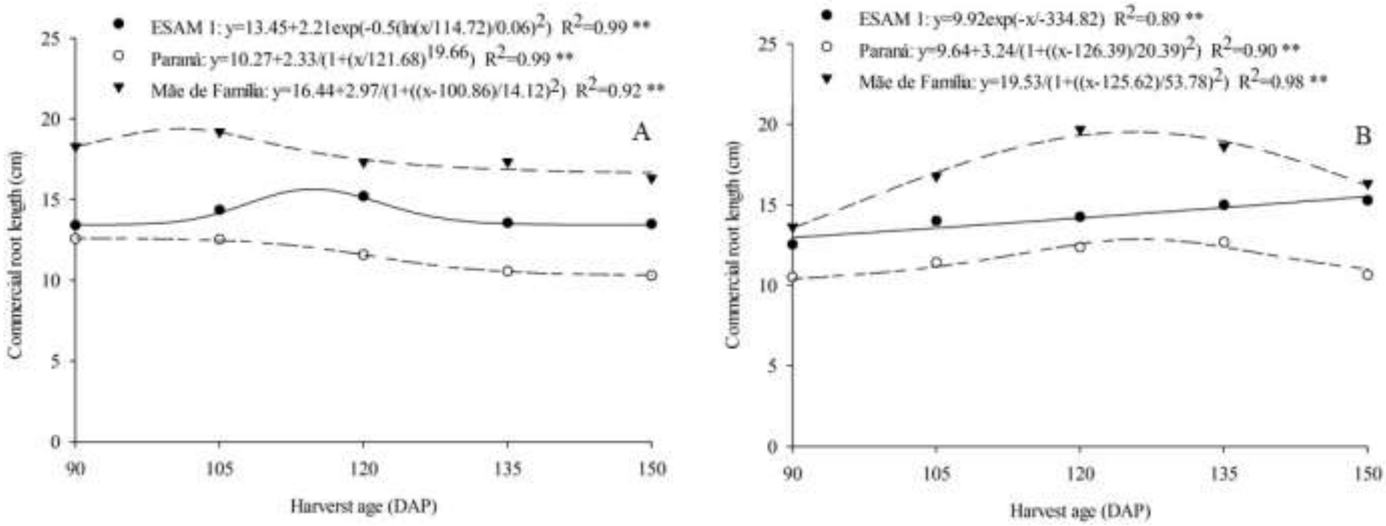

Figure 2. Commercial root length as a function of sweet potato cultivars and harvest ages in two growing seasons (rainy season A and the dry B).

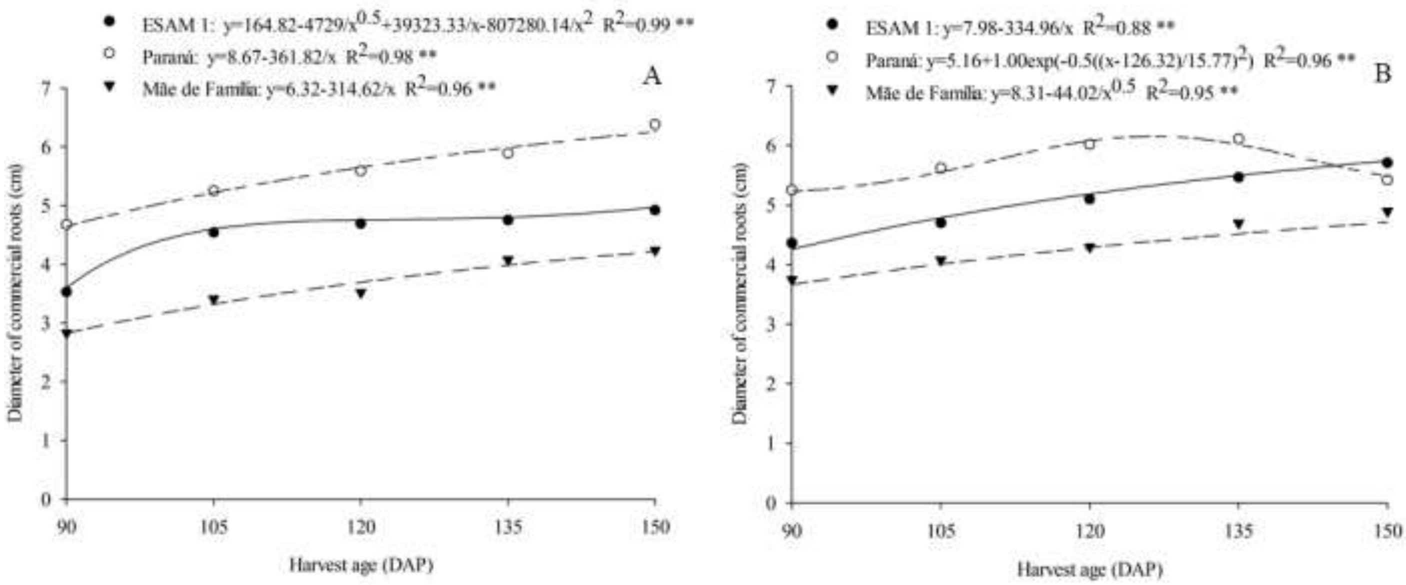

Figure 3. Diameter of commercial roots as a function of sweet potato cultivars and harvest ages in two growing seasons (rainy season A and the dry B).

three sweet potato cultivars (ESAM 1, ESAM 2 and ESAM 3) were studied as a function of the harvest season, in the rainy season of the conditions of Mossoro, where diameters varying of 4.59 to 5.29 cm were observed. These results show that the conditions and cultivation site are crucial in the development of tuberous roots.

Increased growth and diameter of sweet potato commercial roots allow infer that according to the cultivar studied and the conditions in which it is subjected are extremely important to define the material to be grown. According to Miranda et al. (1995), the tuberous roots of sweet potato of best rating (extra A) must have diameter between 5 and 8 cm and length ranging between 12 and 16 cm.

In the second growing season, the sweet potato trade roots showed higher growth and diameter of commercial roots as a function of the age of harvest. These positive results are due probably to the temperature increase in the second semester of the year, with variation of 33-

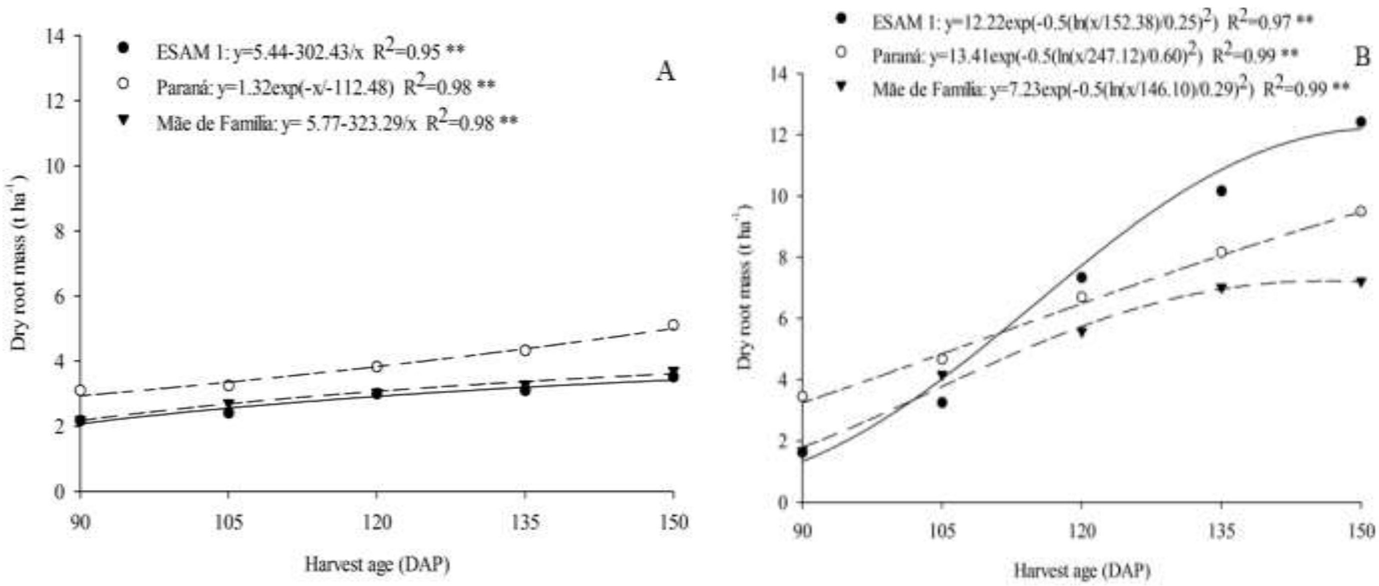

Figure 4. Dry root mass as a function of sweet potato cultivars and harvest dates in two growing seasons (rainy season A and the dry B).

35°C (Figure 1). The optimum temperature for growth of sweet potato roots is about 25°C, with standstill of growth occurring at temperatures below 15°C and above 35°C (Ravi et al., 2009; Spence and Humphries, 1972; Villavicencio et al., 2007). Although, there was temperature of 35°C (Figure 1) during the development of the work, the cultivars showed good performance which may be indicative of good adaptation to growing conditions.

Length and diameter of tuberous roots are among the most important characteristics for good marketing of sweet potato, because the consumer is increasingly demanding with regard to the visual quality of the product, making this a decisive factor when buying.

For producer, these characteristics are fundamental to the choice of material to be produced, given that according to the demand of the consumer market, standards of cultivars to be commercialized can be set.

Thus, the results observed for the cultivars studied shows the potential for improvement in the cultivation of sweet potato in semiarid conditions. It is worth noting that the cultivation at the appropriate time and with appropriate cultivars, not only bring an increase in production but also in the quality of the obtained roots.

In the dry mass of roots (MSR) of sweet potato, it was found that, as the harvest age increased, there was a dry mass increment for all cultivars evaluated in both growing seasons (Figure 4). However, the best time of cultivation was observed in the dry season. It was also observed that the cultivar ESAM 1 expressed higher values of MSR, when compared with the other cultivars in the second growing season, reaching 12.42 t ha^{-1} at 150 DAP (Figure 4B).

The increase of the dry mass of roots in the second growing season may have been caused by the higher incidence of solar radiation, which suffered variation from 27 to 28 MJ m^{-2} day^{-1} (Figure 1). According to Conceição et al. (2004), during the growth period of tuberous roots, high levels of solar radiation combined with suitable temperatures contribute to greater production of total dry matter, and consequently, the highest yield of tuberous roots.

The sweet potato cultivation in the hottest time of year can serve as an alternative for producers who own infrastructure and resources such as water, adding value to the product being offered and getting a higher market value of the marketed product.

The higher values of dry mass of shoots (DMS) were recorded in the first growing season for all cultivars (Figure 5). Regardless of the age of harvest and growing season, the cultivar Mãe de família presented the highest DMS content, reaching 4.20 and 3.20 t ha^{-1} at 90 DAP in the first and second growing season, respectively (Figure 6).

There was still a decreasing linear response for all cultivars, independent of harvest age and growing season (Figure 5). Erpen et al. (2013), evaluating the growing of sweet potato Princess as a function of four planting dates in subtropical climate in the spring summer season, found values close to those found in this work, which ranged from 3.1 to 5.4 t ha^{-1}.

The reduction to shoot dry mass in the first growing season can be attributed to decreased fitomass (Figure 6) at the same season as they are proportional characteristics. According to Spence and Humphries (1972) higher dry matter accumulation occur in the leaf (blade and petiole) per unit area before the formation of the tuberous roots of sweet potato. The activity of the source depends on the demand of assimilates of the drain, there is an interrelationship between the

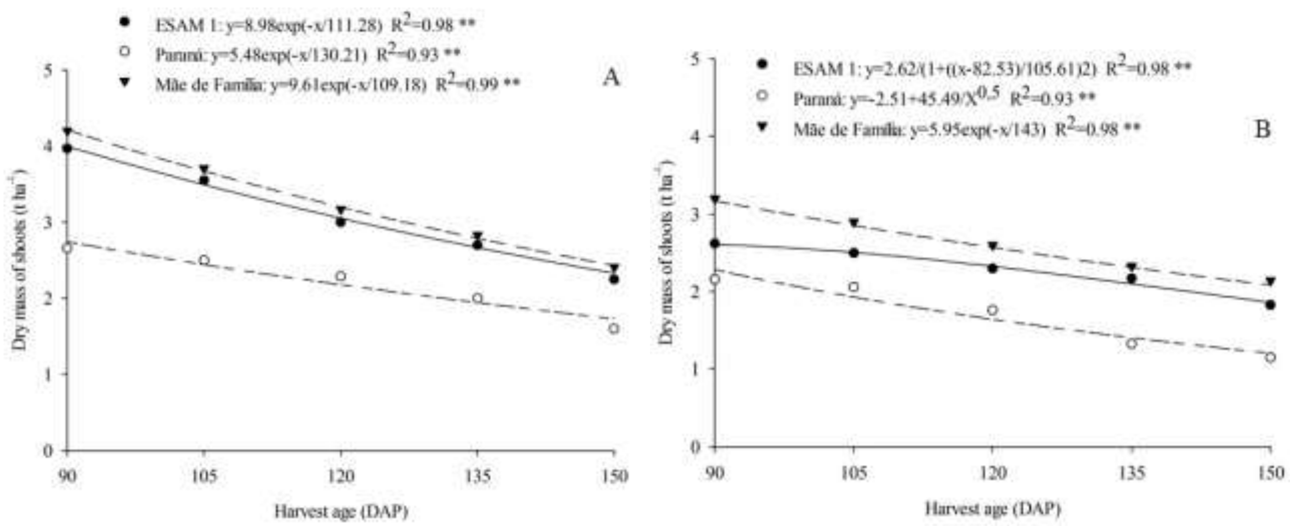

Figure 5. Dry mass of shoots as a function of sweet potato cultivars and harvest ages in two growing seasons (rainy season A and the dry B).

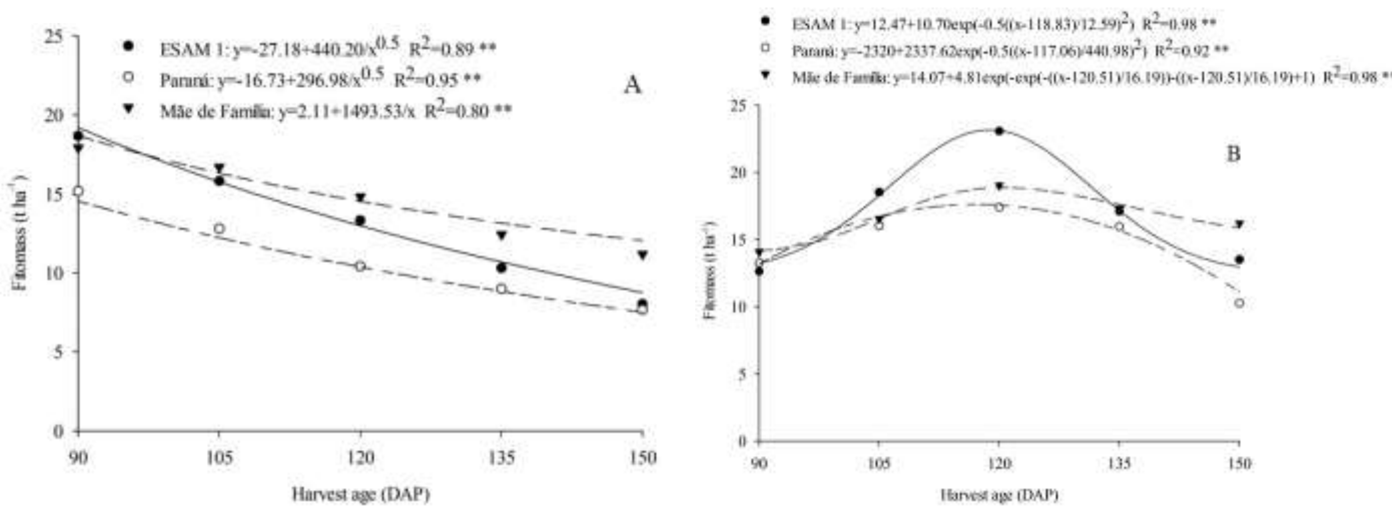

Figure 6. Fitomass as a function of sweet potato cultivars and harvest ages in two growing seasons (rainy season A and the dry B).

photosynthetic rate in the leaf and the storage of assimilated tuberous roots of sweet potato (Hozyo and Park, 1971; Spence and Humphries, 1972).

Evaluating the production of fitomass, maximum value of 120 DAP was observed for all cultivars in the second growing season (Figure 6). It was found that in the first growing season, there was a decrease in the production of fitomass for all cultivars (Figure 6A). The cultivar Paraná showed the lower fitomass production values in both croppings, reaching 7.67 and 10.27 t ha^{-1} in 150 DAP in the first and second growing seasons, respectively (Figure 6).

In this sense, the leaf area (source) is a determinant factor of the production, because its reduction means less absorption of radiant energy and less intense photosynthesis, reducing thus the production of biomass (Oliveira et al., 2010). The production of fitomass is directly reflected in the production; so, the producer can define the best age and harvest time to sell sweet potatoes, and significant gains in income, giving you greater flexibility on the demand and price marketplace. Additionally, you can also use fitomass as animal feed.

It is believed that the decrease in fitomass production is linked to senescence and leaf abscission and death of plants. Whereas harvest ages, with the increase of plant cycle, usually occur with reduction of leaf area due to senescence, and leaf abscission, but with favorable conditions for vegetative development of fitomass

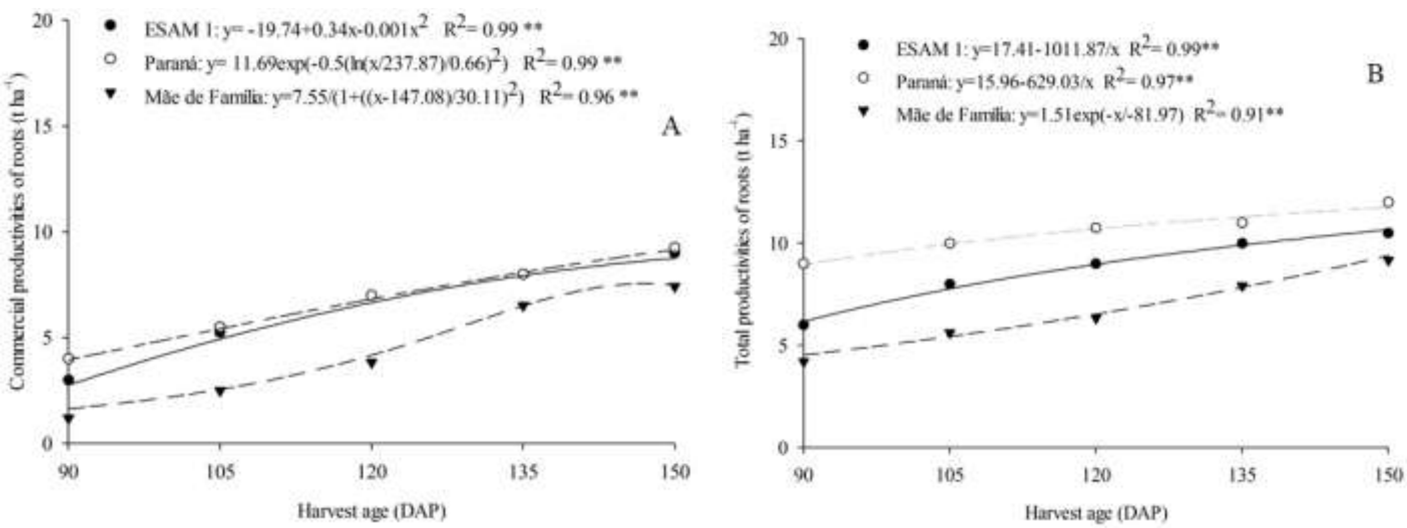

Figure 7. Commercial and total productivities of roots as a function of sweet potato cultivars and harvest ages in the rainy season.

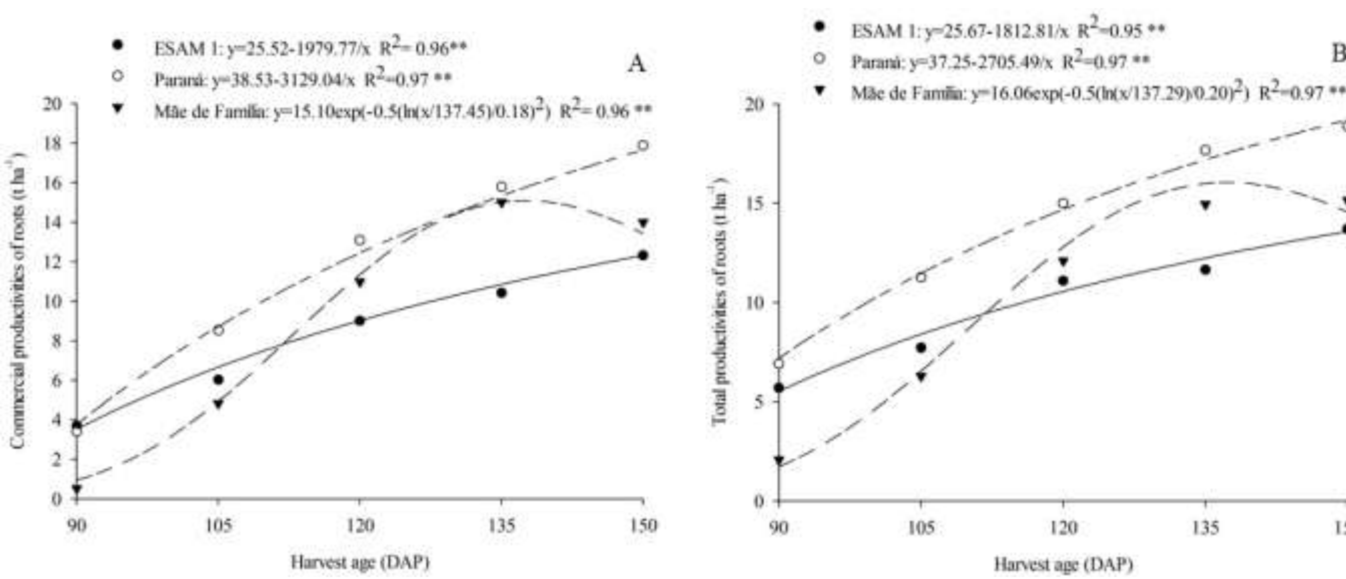

Figure 8. Commercial and total productivities of roots as a function of sweet potato cultivars and harvest ages in the dry season.

production can be maintained at high levels (Figueiredo, 1993).

The fitomass production values found in this work can be justified also by higher productivity index obtained at 150 DAP (ESAM 1 9.0 t ha^{-1}, Paraná 9.25 t ha^{-1} and Mãe de família 7.50 t ha^{-1}) for all cultivars, demonstrating that in this time, the preferred metabolic drain were the tuberous roots and not the shoot.

For the commercial productivity of roots (CPR) and total root productivity (TRP) in the homogeneity of variances was not accepted, thus performing a separate analysis of the experiments. From these results, there was a significant interaction (age x cultivar) in both croppings.

In the first growing season, regardless of the harvest age, the cultivar Paraná showed the greater commercial and total productivities roots, reaching 9.25 and 12.0 t ha^{-1} at 150 DAP, respectively (Figure 7A and B). It was also observed that all cultivars expressed an increasing linear response with respect to harvesting age.

In the second growing season, regardless of the harvest age, the cultivar Paraná showed the greater commercial and total productivities roots, reaching 17.67 and 18.89 t ha^{-1} at 150 DAP, respectively (Figures 8A and B). The cultivar Mãe de família showed a decreasing in the commercial productivity as from 135 DAP. It was also observed that all cultivars showed an increasing linear response with respect to harvesting age for full productivity.

Evaluating five sweet potato cultivars and two harvest seasons (150 and 200 days after planting) in the North of Minas Gerais, in the summer-autumn, Resende (2000) obtained an increase in productivity of all cultivars at 200 DAP, attributing the results to the longest period of crop permanency in the field. Queiroga et al. (2007) obtained an increase in the productivity at 155 DAP.

The source-drain relationship may also have been decisive in this respect, with the reduction of the shoots occurring in the largest production of tuberous roots. The production of the tuberous root is a function of the drain capacity and the potential of the source (Conceição et al., 2004). The sweet potato is a perennial crop, tuberosity continuously under favorable conditions, so that the longer the duration, the start of tuberosity-harvest allows more time for the accumulation of assimilates in the roots (Erpen et al., 2013).

After the beginning of the tuberosity initiation, productivity depends on the capacity of shoots to produce assimilated ones and translocate them to the roots (Somasundaram and Mithra, 2008). Consequently, high levels of solar radiation positively affect productivity of roots, since this variable is the energy source for photosynthesis.

Similar behavior was observed in both growing seasons, showing thus, positive responses with increasing harvest age. These positive results are due probably to the greater accumulation of assimilates in the tuberous roots due to longer time of the plant in field.

Thus, the producer can anticipate the harvest in 20 days without loss, or put it off for an equal time with significant gains in income, giving it greater flexibility on the demand and market price (Queiroga et al., 2007). In addition, the cultivar, Paraná was efficient in the absorption of resources, resulting in a good production, showing its productive potential in the region.

Conclusions

The sweet potato cultivar, Paraná showed the largest diameter of commercial roots, with the lowest increments of shoots and the highest commercial productivity of roots. At the age of harvest of 150 days after planting, the best agronomic results was observed for diameter of commercial roots, total dry mass of roots, commercial and total productivities of roots. The best cultivation season was observed in the 'dry' period. This work can be reproduced anywhere in the world, since the producers or researchers have knowledge of the agro-meteorological factors involved in the productive system, which can directly influence the productivity of the culture.

Considering the importance of sweet potatoes, further studies are recommended in order to solve some problems related to adaptability and cultural reproduction in other regions to elucidate the effects of harvesting ages and growing seasons at longer intervals.

Conflict of Interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Traps to capture fruit fly *Ceratitis capitata* Wiedemann (Diptera: Tephritidae)

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The aim of this study was to determine trap efficiency on capturing fruit fly *Ceratitis capitata.* The research was conducted in greenhouse of the Entomology Laboratory of the Department of Plant and Environmental Sciences, Agricultural Sciences Center of the Federal University of Paraiba – CCA/UFPB, Areia – PB. The trap efficiency was evaluated by comparing three types (Delta, Pet and Circular Trap) with standard trap of McPhail type using liquid and semi-solid lures: Bio Anastrepha® 5% and CeraTrap®. Traps were equidistantly arranged in the experimental environment where eight releases of 300 adults of *C. capitata*, newly emerged, were carried out. The effectiveness of traps was evaluated according to the number of captured flies in the set period. Data were subjected to variance analyses and Tukey test. Standard trap of McPhail type and alternative trap of Pet type were the most efficient on capturing *C. capitata* in greenhouse environment. The alternative trap of Pet type can replace the standard one on *C. capitata* trapping.

Key words: Fruit production, hydrolyzed proteins, Mediterranean fruit fly.

INTRODUCTION

A large part of the damage is done on the global fruit production due to the infestation of fruit flies as a result of direct and indirect damage caused by oviposition of these insects in fruits (Zucchi, 2012). Direct damages are from pulp consumption for their larvae and indirect are caused by entry of pathogens in holes during oviposition (Lozano-Tovar et al., 2015), both make fresh consumption of fruits impossible by invalidating fruit marketing, not only by the depreciation of fruit quality but also due to quarantine restrictions imposed by importing countries (Raga et al., 2006). Thus, there are a phytosanitary barrier in the marketing of fresh fruit to the United States and some European countries (Carvalho, 2005; Zucchi, 2008).

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Mediterranean fruit fly, *Ceratitis capitata* Wiedemann (Diptera: Tephritidae), is one of Tephritidae species which has polyphagous food habit and has wide distribution throughout the world and is considered one of the most damaging species, focusing on more than 350 species of plants (Carvalho, 2005). It was introduced in Brazil in the early century (Gallo et al., 2002) and is already present in 24 states, associated with 58 fruit species of 21 families (Zucchi, 2012; Lozano-Tovar et al., 2015).

The production of fruit in Brazil has achieved significant technological advances, but still has serious problems regarding the quality of produced fruit, some attributed to phytosanitary restrictions required by importing countries (Bittencourt et al., 2006). From these requirements is difficult to establish control measures of insect pests. Measures have to fit producer conditions and different production areas of national fruit production (Raga, 2006).

Fruit flies monitoring is a key part to control start of these insects in any integrated management system of pests (Malavasi and Zucchi, 2000). By monitoring, it will be possible to characterize these tephritids, and know the exact moment for a proper control measure. Thus, the use of traps is essential because monitoring efficiency and control of fruit flies are associated with the quality of traps and baits used and its arrangement in field. The most common type of trap used to capture these tephritids is the commercial trap, McPhail (Barros et al., 1991; Lasa et al., 2013, 2014a, 2015), but it can also be used some alternative models made of recycled materials and/or lower cost than commercial product using the same principle, which is the adults lure with food baits without distinction of species (Lasa et al., 2013, 2014b).

Lasa and Cruz (2014), comparing McPhail trap with the alternative of transparent bottles with holes on the side combined some protein lure. They found that alternative trap was more efficient on capturing *Anastrepha ludens* Loew (Diptera: Tephritidae). Khater et al. (1996) achieved excellent results in the use of yellow sticky traps on *Bactrocera oleae* Rossi (Diptera: Tephritidae) monitoring in olive orchards (*Olea europaea*). By associating different lures in McPhail traps and in alternative traps adapted from transparent bottles. Scoz et al. (2006) reported similar efficiency on *Anastrepha fraterculus* Wiedemann (Diptera: Tephritidae) capturing. Within this perspective, the objective of this research was to determine the efficiency of traps associated with food lures in adult *Ceratitis capitata* trapping.

MATERIALS AND METHODS

The research was conducted in a greenhouse environment (anti-aphid screen) with dimensions of 9 x 6 m, covered with transparent acrylic plastic, and in Entomology Laboratory both are from the Department of Plant and Environmental Sciences, Agricultural Sciences Center of the Federal University of Paraiba– CCA/UFPB, Areia – PB, with 12 h photoperiod, temperature and relative humidity not controlled.

Rearing of *C. capitata*

The adults of *C. capitata* used in research were derived from a mass rearing maintained at the Entomology Laboratory of the Department of Plant and Environmental Sciences of the Agrarian Science Center of University Federal of Paraiba – CCA/UFPB, Areia – PB, reared according to the methodology described by Brito (2007) at temperature of 25 ± 1°C, relative humidity of 70 ± 10% and photoperiod of 12 h.

Evaluation of traps to capture *C. capitata*

For evaluation of traps to capture *C. capitata*, three types of traps were made: Delta type trap made of paper wrapped by a plastic and recovered with entomological glue; Pet type trap made from a 500 mL transparent bottle with three circular openings of 1.5 cm diameter at the top equidistant; Circular trap made of transparent polyethylene surrounded by entomological glue on inside, with three circular openings of 1.5 cm diameter at the top equidistant. The three types of traps were suspended by galvanized wire.

In each type of trap, two types of food lures were used, hydrolyzed protein Bio Anastrepha® (Bio Control, São Paulo, Brazil) and CeraTrap® (Bioibérica S.A, Barcelona, Spain) in liquid and semi-solid form. In McPhail and Pet traps were placed 325 ml of liquid lure/trap. CeraTrap® was used without dilution and Bio Anastrepha® was diluted in water at 5%, both as recommended by the manufacturer. For the use of semisolid lure, both were lyophilized and concentrate content was placed in plastic adapted container (1.5 x 1.0 cm), suspended for a galvanized wire on top and inside of Circular and Delta type traps.

To compare the effectiveness of these traps, a design consisted of randomized blocks in a factorial scheme (4 x 2 x 2 x 4) was conducted: Four traps with type McPhail trap as a witness, two lures (Bio Anastrepha® and CeraTrap®), both sexes (adult males and females), and four replications. Treatments were arranged in the greenhouse environment at a distance of 4 m from the center, with a circular container of transparent plastic (15 x 30 cm) containing circular openings of 1.5 cm in diameter, which 300 adults newly emerged were released in the proportion 1:1 of *C. capitata.* Traps with lures and container with insects were suspended at 1.5 m height.

A total of eight releases were carried out (at five-day intervals), in order to trap/lure combination at same position in the greenhouse environment, at each release lure of traps were also renewed.

Statistical analysis

The efficiency of traps evaluation was conducted from the number of insects captured after 24 h of release, females and males were recorded. The collected experimental data were submitted to variance analyses and Tukey test at 1% probability.

RESULTS AND DISCUSSION

From variance analysis can be observed that there was a statistical significance for traps ($F = 79.50$; $p < 0.0001$), for sex ($F = 231.60$; $p < 0.0001$) and traps x gender interaction ($F = 50.65$; $p < 0.0001$) on the capture of *C. capitata* (Table 1).

Standard traps of McPhail type and alternative of Pet type were effective on capturing fruit flies *C. capitata* in greenhouse environment, accounting for 48.79 and

Table 1. Variance analyses for fruit flies, *Ceratitis capitata* captured in different traps installed in greenhouse environment.

VS	DF	SS	MS	F	P>F
Trap (T)	3	4885.17	1628.39	79.50	0.0000**
Block	3	60.92	20.30	0.99	0.4048^{ns}
Lure (L)	1	31.64	31.64	1.54	0.2199^{ns}
Gender (G)	1	4743.76	4743.76	231.60	0.0000**
(T) x (L)	3	43.29	14.43	0.70	0.5539^{ns}
(T) x (G)	3	3112.67	1037.55	50.65	0.0000**
(L) x (G)	1	54.39	54.39	2.65	0.1097^{ns}
Error	48	983.12	20.48	-	-

VS = variation source; DF = degrees of freedom; SS = sums of squares; MS = middle-square; F = Test F; P>F = significance; ^{ns}no significance; **significant at P<0.01 probability error.

Table 2. Average number of adults captured fruit flies, *C. capitata* in traps installed in greenhouse environment under the influence of different food lures (mean ± SE).

Traps	Total number of captured insects	
	Lures	
	Bio Anastrepha®	CeraTrap®
Delta type	4.25 ± 1.26^{bA}	4.62 ± 1.60^{bA}
Pet type	17.25 ± 2.34^{aA}	17.87 ± 5.61^{aA}
Circular	0.37 ± 0.26^{bA}	0.75 ± 0.36^{bA}
McPhail	19.37 ± 6.25^{aA}	23.62 ± 7.59^{aA}

Means followed by the same letter, in column and capital in line, do not differ significantly at 1% probability by Tukey test.

39.85% of the total adults trapping, respectively (Table 2). However, traps have no statistical differences when compared within each lure. Despite the acquisition and maintenance costs, traps of McPhail type are commonly used in monitoring and tephritids control, being more efficient than traps that use dry baits. They are even more effective in dry season, by providing food and water, facilitating the search and capture of flies (Perea-Castellanos et al., 2015). Thus, it still needs further studies to explore the association of a trap with less expensive lure. The solution may be the traps that use the same action mechanism and cost less due to its reusable material. The results of this study indicate that trap of Pet type had similar efficiency as compared to standard trap of McPhail type.

In several experiments conducted by Scoz et al. (2006) under various conditions, the alternative model of trap, made from Pet bottles, was equivalent to McPhail model in the capture of *A. fraterculus* adults. Aguiar-Menezes et al. (2006) found the efficiency of fly trap bottle made from Pet transparent bottles by protein hydrolyzate 5% as bait, whose results suggested that this trap type is equal or sometimes superior to McPhail standard trap on the capture of *Anastrepha* spp. and *C. capitata.*

Lasa and Cruz (2014) compared McPhail trap with the alternative made of transparent bottles with holes on the sides, combined some protein lures, and found that alternative trap with Cera Trap® was more efficient on capturing *A. ludens.* Rodríguez et al. (2015) found that Cera Trap® associated with inexpensive traps made of transparent bottles were effective in the control of *A. serpentina* Wiedemann (Diptera: Tephritidae). However, Duarte et al. (2013) used Moscatex® lure (pure or mixed with guava juice) and found that McPhail trap was more efficient than the weak fly trap in the capture of *Anastrepha* spp. and *C capitata.*

The superiority on *C. capitata* capturing of standard traps of McPhail type and Alternative of Pet type as compared to traps of Circular and Delta type can be directly related to lure ability or dispersion of lure substances of liquid product as compared to semi-solid. Some research has shown the greatest trapping ability with liquid bait as compared to solid baits (Pingel et al., 2006; Thomas et al., 2008).

Research on this topic reported that not all flies that come into McPhail traps are captured. Aluja et al. (1989) and Díaz-Fleischer et al. (2009) stated that approximately 20% of the flies that come into the trap are able to feed and escape. It is a risk when uses no lures combined with chemicals. There is the possibility that these flies only get protein needed to reach sexual maturity.

Regarding the number of *C. capitata* females captured by different traps, it was found that there was a significant difference, especially McPhail trap, with an average of 38.87 females/trap (Table 3). Regarding the capture of males, no significant difference was observed between different traps. In all the traps, with exception of circular, the average adult females captured were higher than the captured male mean. In total, 90% of females and only 10% of *C. capitata* males were captured.

With similar results to this study, Azevedo et al. (2012) verified the efficiency of traps adapted from plastic bottles and liquid lure Bio Anastrepha® when compared with other lure substances and a number of adult female higher than male captured was also observed for both *Anastrepha* spp. and *C. capitata.* Lasa and Cruz (2014) and Lasa et al. (2014a) verified the superiority of traps adapted from plastic bottles on McPhail standard trap when combined with Cera Trap® liquid lure in the capture of *A. obliqua* Macquart (Diptera: Tephritidae) females.
Research that used traps with the same capturing principle of McPhail and type Pet traps confirmed the superiority on capturing females as compared to males of fruit flies (Raga, 2006; Lasa et al., 2013; Nunes et al., 2013; Lasa and Cruz, 2014; Rodrigues et al., 2015).

Monitoring is important for conducting research on the behavior of these tephritids in field, acting as alert for control started at the right time. Evaluation of low-cost traps and effective and reliable food lures must constantly

Table 3. Average number of adults captured fruit flies, *C. capitata* in traps installed in greenhouse environment (mean ±SE).

Traps	Total number of captured insects	
	Sex	
	Female	Male
Delta type	7.87 ± 0.74^{cA}	1.0 ± 0.50^{aB}
Pet type	30.87 ± 1.54^{bA}	4.25 ± 0.99^{aB}
Circular	0.87 ± 0.39^{dA}	0.25± 0.16^{aA}
McPhail	38.87 ± 4.00^{aA}	4.12 ± 0.76^{aB}

Means followed by the same letter, tiny column and capital in line, do not differ significantly at 1% probability by Tukey test.

be performed (Scoz et al., 2006) for practice success, because cost is an important factor for the choice of trap for monitoring and control of insects, especially concerning small properties. Traps of plastic bottles can be an excellent option to capture diptera, due to its efficiency and cost reduction in fruit production.

Some authors such as Barros et al. (1991) and Lorenzato (1984) have different opinions on the use of traps adapted from plastic bottles. The first stated that these models when compared to McPhail trap are less effective on *A. fraterculus* capturing. The second shows that there is similarity on fruit flies capturing when two models were used, and indicate traps of plastic bottles, because the cost is an important criterion in the choice of a good trap for monitoring and control.

To capture adults of diptera is a good option to reduce the damage caused to the fruit production. However, this method should be associated with others within the integrated management system of pests for greater effectiveness. Method adoption by producers is required to offer some advantages beyond efficiency, such as, economic viability and practicality. Therefore, further studies that associate best the combination of traps and lures are necessary.

Conclusion

The Pet trap type is an alternative to capture *Ceratitis capitata* females when associated with Bio Anastrepha® and/or CeraTrap® lures.

Conflict of Interests

The authors have not declared any conflict of interests.

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